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SEASONAL ABUNDANCE OF THE CORN EARWORM [1]

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INTRODUCTION

Estimates of the abundance of the corn earworm (*Heliothis armigera* (Hbn.) [3]), also called the tomato fruitworm and the cotton bollworm, are commonly based on the degree of infestation observed on the affected hosts or, in some instances, on the number of complaints of of injury received from growers. Workers engaged in the study of this pest have usually gaged its abundance during its active season by making egg counts at regular intervals, by measuring the larval injury throughout the season, or by a combination of these two methods.

In central Virginia and the territory adjacent to the District of Columbia, the areas included in this study, the great mass of the corn earworm population occurs on corn (*Zea mays* L.). It is generally agreed that corn is the preferred host plant, and also that the fresh silk is the most attractive part of the corn plant for oviposition. Except in the late-maturing fields, where egg laying is prolonged because more attractive host material is not becoming available, in a particular cornfield oviposition reaches its maximum at or shortly after the time when the corn reaches its maximum silking stage. The moths emerging from hibernating pupae early in the season, before corn becomes attractive for oviposition, deposit eggs on a variety of hosts, a common one being tomato. With the appearance of early attractive corn there is a shift to this plant, and the insect remains concentrated on corn for about 2 months, or until the grain in late-maturing fields hardens, when there is again a decided shift to a variety of hosts, common examples of which are tomato, alfalfa, and particularly cotton in the South.

In 1932 work was begun in the vicinity of Charlottesville, Va., to develop methods for obtaining a better understanding of the seasonal population on corn. With the discontinuance of the Charlottesville laboratory in 1933, this study was suspended until 1934, when observations were resumed at Arlington, Va., adjacent to the District of Columbia. In this area, in addition to seasonal abundance, the factors that affect the abundance from year to year were also given consideration.

The results of these investigations are of particular value in the

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[3] This is now considered to be the correct scientific name for the corn earworm instead of *H. obsoleta* (F.). See the following: HEINRICH, CARL, THE PROPER NAME FOR THE CORN EARWORM. Jour. Econ. Ent. 32: (In press.)

interpretation of the infestations in varietal test plots, where the evidence of relative susceptibility to oviposition may be distorted by a difference in maturity of the corn.

REVIEW OF LITERATURE

The published accounts of the seasonal life history of *Heliothis armigera* reveal a difference of opinion as to both the number of generations [4] per year and the time of the appearance of the various generations. The usual procedure for determining the life span of a generation has been by interpolation of data on egg counts made at regular intervals and seasonal rearings made in the insectary. It is generally agreed that under optimum conditions during the summer a generation is completed in about a month.

Quaintance and Bishopp (*13*) [5] estimated the number of generations occurring annually in the Cotton Belt as from four to seven, depending on the latitude. Barber (*1*) observed from one to six generations in southeastern Georgia, with generations overlapping so that they were indistinguishable, and he found that dormancy in pupae began as early as June. Isely (*8*) estimated the number of generations in Arkansas as probably four. He reviewed the records on the depredations of *Heliothis armigera* as a pest of corn, cotton, soybean, grain sorghums, tomato, and alfalfa over the 25-year period 1911–35, and stated that severe damage occurred in the State on one host or another in 9 of these years. Of interest is his observation that the outbreaks were most frequent in a group of counties in which the acreages of corn and of cotton were about equal and that a county bordering this group, in which the acreage of cotton was about four times that of corn, was never involved in an outbreak.

Northward from the Cotton Belt *Heliothis armigera* normally decreases in abundance and is most common on corn, tomato, and alfalfa. Garman and Jewett (*6*) estimated three generations at Lexington, Ky., between June 10 and September 12, and a fourth imperfect generation early in November. In a study of the seasonal fate of eggs of the corn earworm at Charlottesville and Richmond, Va., during the 4-year period 1924–27, Phillips and Barber (*10*) found that the percentage of eggs hatching between July 1 and September 1 did not vary greatly.

Headlee (*7*) gave an account of the seasonal abundance of eggs in the field at Manhattan, Kans., in connection with a study for determining the best planting date for field corn to avoid earworm injury. From rearings and regular egg counts he estimated that there were three generations and a partial fourth which did not mature. He considered that the great increase in the number of eggs per plant during the latter part of August and September was due to the great abundance of the third brood of moths. The corn planted on May 1 was found to bear the least injury. Similar studies continued by McColloch (*9*) at Manhattan, Kans., from 1913 to 1918 led to substantially the same conclusions. He fixed the time of maximum emergence of the broods as follows: First, June 15; second, July 13, and third, the last days of August and the first days of September. In

[4] The term "generation" in this paper is used to include a complete life cycle from the egg to the adult. The term "brood" is applied to a stage of the insect within a life cycle; e. g., the moths emerging from the overwintering pupae are the first brood of moths.

[5] Italic numbers in parentheses refer to Literature Cited, p. 257.

comparison with the third generation, the first and second generations were considered of little importance.

Ditman and Cory (*3*, *4*) concluded that in Maryland there are usually not more than two generations, although theoretically moths emerging early in the spring would produce three generations, or even four, in a long summer season. They further concluded that "generations overlap to such an extent that there is a regular and gradual building up of the corn earworm population from the beginning to the end of the season." Ditman and Cory (*5*) observed a slight depression in infestation in sweet corn maturing the last week of July and the first week of August from that in earlier maturing corn.

In central Virginia Phillips and Barber (*10*) found that in corn planted at weekly intervals from April 18 to June 26 egg deposition was usually the lightest in the plantings from May 8 to 29. Plantings from April 18 to May 2 usually received the next largest number of eggs, and the plantings in June the largest number. These writers concluded that corn planted in midseason (May 8–29) received the fewest eggs because it silked between the appearance of the first and second broods of moths. They consider the second brood as the one causing the heavy infestations in the late-planted corn coming into silk the latter part of August. In the same area Phillips and Barber (*11*) found the smallest reduction in yield due to the corn earworm, both in experimental plots and in the field, in corn planted before May 15.

EXPERIMENTS AT CHARLOTTESVILLE, VA.

EGGS

In earlier experiments at Charlottesville Phillips and Barber (*11*) found that infestations in contiguous plantings of corn made at regular intervals were heavier than those occurring under field conditions. They believed this to be brought about by a concentration of ovipositing activity in the small early plantings, resulting in the building up of an infestation in the later plantings by successive generations. To avoid this unnatural condition in the experiments conducted during 1932, plots of sweet corn (*Zea mays* var. *rugosa* Bonafous), planted at more or less regular intervals were established in cornfields in the vicinity of Charlottesville, separated far enough from one another to eliminate the chance of building up an infestation adjacent to each planting. Egg counts were made at random in these plantings on silks attractive for oviposition (2 to 5 days after they emerged from the ear shoot) and on some additional smaller plantings that silked after this group had ceased to be attractive for oviposition. Egg counts were made every other day, the number of samples depending on the number of plots in fresh silk. The size of the samples ranged from 5 to 30 silks, most of the larger samples being taken in midsummer, when the rate of oviposition per silk was low. Table 1 summarizes these data for the period July 12 to October 29, inclusive.

The number of eggs deposited per silk decreased abruptly following the 10-day period July 12–21 and did not increase appreciably until the latter part of August. The rate of oviposition continued at a high level throughout September, reaching a peak during the period September 20–29, after which there was an abrupt decrease, the last egg being recorded in the period October 10–19. The seeming decrease

in the abundance of eggs the latter part of July and the early part of August at first appeared to be due to a scarcity of moths. General observations in the surrounding area, however, indicated that the increased abundance of field corn attractive for oviposition resulted in a decrease only in the number of eggs per silk.

TABLE 1.—*Seasonal abundance of eggs of the corn earworm on separated plantings of sweet corn in cornfields near Charlottesville, Va., 1932*

Period of sampling	Samples	Silks	Eggs	Average eggs per silk	Period of sampling	Samples	Silks	Eggs	Average eggs per silk
	Number	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*
July 12–21	11	75	75	1.00	Sept. 10–19	6	35	77	2.20
July 22–31	19	95	17	.18	Sept. 20–29	5	25	60	2.40
Aug. 1–10	20	150	16	.11	Sept. 30–Oct. 9	5	25	13	.52
Aug. 11–20	30	275	28	.10	Oct. 10–19	5	25	1	.04
Aug. 21–30	17	110	33	.30	Oct. 20–29	4	20	0	.00
Aug. 31–Sept. 9	13	76	170	2.24					

LARVAL INFESTATIONS IN SEASONAL PLANTINGS

The percentage of ears infested with larvae of the corn earworm in the separated field plots on which egg counts were made on the silks as recorded in table 1 is shown in table 2. The trend of the infestation was from high in plots reaching maximum silking July 15–25 to low in plots reaching maximum silking August 5–9, followed by a rapid increase in the plots reaching their maximum silking after that date.

TABLE 2.—*Percentage of earworm-infested ears in seasonal plantings of sweet corn made in separated cornfields near Charlottesville, Va., 1932*

Planting date	Period when fresh silks were present	Date of maximum fresh silks	Ears examined	Ears infested
			Number	*Percent*
Apr. 21	July 8–22	July 15	54	68.6
May 3	July 19–30	July 25	100	93.0
May 17	July 18–Aug. 3	do	54	75.9
May 30	July 24–Aug. 17	Aug. 5	100	23.0
June 9	Aug. 1–19	Aug. 9	100	19.0
June 20	Aug. 9–Sept. 2	Aug. 21	100	35.0
July 2	Aug. 18–Sept. 4	Aug. 26	100	72.0
July 15	Aug. 30–Sept. 11	Sept. 5	55	94.5

The seasonal percentage of ear infestation and the seasonal abundance of eggs are shown graphically in figure 1. It will be readily seen that there is a direct correlation between these two factors. General observations in the vicinity of Charlottesville showed that the period July 22–August 20, when there was a seeming scarcity of eggs and a resultant low percentage of ear infestation, was the period when most of the acreage of field corn was in the stage of silking most attractive to the moths for oviposition. Over the area as a whole the earworm was much more abundant during the period of low percentage infestation than was shown by either the number of eggs per silk or the percentage of ear infestation. Moreover, there was evidence that the

high infestations found in plots early in July, late in August, and in September were not an accurate measure of the general abundance of the earworm or the aggregate injury to corn during those periods. It was obvious that a record of the seasonal abundance of corn attractive for oviposition was essential to the determination of the seasonal abundance of the insect as well as of its degree of injury.

EXPERIMENTS AT ARLINGTON, VA.

OBSERVATIONS ON LIFE HISTORY

In northern Virginia the corn earworm hibernates more or less successfully. During the period 1933–37 pupae survived the winter in hibernation cages at Arlington Experiment Farm each year. In this period there were two winters with below-normal temperatures (one of which was severe), one winter with temperatures slightly above normal, and one very mild. The earliest emergence of moths

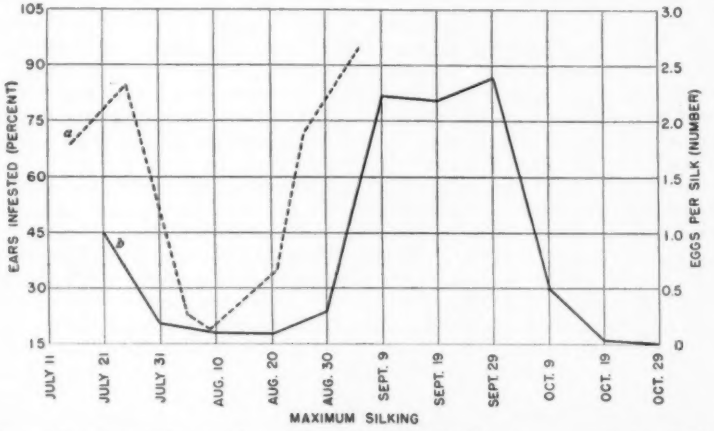

FIGURE 1.—Seasonal percentage of ear infestation by the corn earworm in relation to the seasonal abundance of eggs per silk, Charlottesville, Va., 1932: *a*, Percentage of ears infested; *b*, number of eggs per silk.

in hibernation cages was on June 4, in 1937, and the latest emergence on July 14, in 1934. Although pupae survived the severe winter of 1935–36, no emergence of moths was recorded that year. At Charlottesville, Va., where the climate is somewhat milder than at Arlington, the earliest emergence of moths recorded by Barber and Dicke (*2*) during the period 1928–33 was on May 25, 1933, and the latest emergence on August 5, 1929. More than 50 percent of the moths emerging from hibernation in cages issued after July 1. Field observations at Arlington during the past 4 years indicate that the effect of cage conditions is to delay emergence of moths from overwintering pupae.

Observations on the first appearance of eggs in the spring were made at Arlington during the period 1934–37. In 1934 the first eggs were recorded on May 18, in 1935 on June 3, in 1936 on May 22, and in 1937 on May 28. In 1935, 1936, and 1937 corn started in the greenhouse in March was used to attract the earliest appearing

moths. In 1937 corn with attractive silks was available in field plots after May 10, but no eggs were found until May 28.

Many workers have made rearings of the corn earworm and have found that a generation is completed in approximately 30 days when eggs are deposited late in June, in July, and early in August. A generation developing from eggs deposited by early-emerging moths late in May requires longer, as do the offspring of moths emerging after August 15. The time required to complete a generation on green corn during the summer varies to a large extent with the temperature. In 1934 insectary rearings were made for two complete and a partial third generation. Eggs deposited June 15, which was almost a month after the first eggs were found in the field that year, produced mature larvae which entered the soil by July 1, and issued as moths from July 15 to 21. Larvae obtained from eggs deposited by these moths on July 17 and 18 became full grown and entered the soil from July 28 to August 10, and the moths issued from August 14 to September 10. Larvae from eggs deposited the third week of August became full grown during the fall of 1934. There was no emergence of moths from individuals placed in cages during the second week of September.

Under field conditions in 1936, on Golden Cross Bantam sweet corn with egg deposition as early as May 22, the first larvae entered the soil for pupation on June 16. In 1937, on similar sweet corn with egg deposition beginning May 28, the first larvae entered the soil on June 14.

Without doubt the second brood of moths was abroad in the field in northern Virginia the first week of July during 1936 and 1937, and the first progeny of this generation, or the third brood of moths, appeared early in August. These observations confirm the findings of McColloch (*9*) in Kansas and of Ditman and Cory (*3*) in Maryland. The overlapping of the first and second generations early in July makes the generations lose their identity and results in a gradual increase in the population with the peak late in the summer. With emergence of moths from hibernation covering about a month and a half, it is doubtful whether peaks in oviposition during July and August definitely signify the maximum moth population of a particular brood. The number of complete generations can consequently be only an estimate. It is believed that in the vicinity of the District of Columbia two generations are usually completed, with a considerable part of a third generation often produced.

LARVAL INFESTATION IN SEASONAL PLANTINGS OF SWEET CORN

With the establishment of the corn earworm project at Arlington Experiment Farm, in 1934 and 1935 plantings were made at intervals of about 15 days, beginning May 1, in a single block. The larval infestations observed in these plots are summarized in table 3. The percentage of infestation showed the same seasonal trend as that at Charlottesville in 1932, the plots planted early and those planted late being most heavily infested.

Upon comparison with the seasonal abundance in field corn for the same years (table 5), the seasonal plantings show a much heavier infestation. As has been pointed out, this apparently is due to a concentration of eggs on a small planting of early attractive corn and a subsequent building up of an infestation in successive plantings.

Successive plantings of small plots consequently do not give a true picture of the seasonal abundance of the earworm.

TABLE 3.—*Percentage of infestation of the corn earworm in seasonal plantings of Golden Cross Bantam sweet corn, Arlington Experiment Farm, Va., 1934 and 1935*

Planting date [1]	Date of beginning of silking	Date harvested	Ears infested	Planting date [1]	Date of beginning of silking	Date harvested	Ears infested
1934			*Percent*	*1935*			*Percent*
May 1	July 2	July 25	88.0	May 1	July 12	July 27	93
May 16	July 16	Aug. 3	61.0	May 15	July 17	Aug. 8	52
May 29	July 23	Aug. 10	81.8	May 29	July 24	Aug. 13	62
June 12	July 30	Aug. 20	87.8	June 11	Aug. 5	Aug. 21	77
June 26	Aug. 13	Sept. 4	99.3	June 25	Aug. 12	Aug. 29	88
				July 10	Aug. 28	Sept. 27	100

[1] In 1934, 4 plots were planted on each date and in 1935 only 1 plot. In each plot 100 ears were examined.

SEASONAL ABUNDANCE OF EGGS IN RELATION TO SEASONAL ABUNDANCE OF CORN ATTRACTIVE FOR OVIPOSITION

In 1936 egg counts on silks attractive for oviposition were made at Arlington throughout the silking period. The seasonal abundance of corn in attractive silk was similar to that in the representative group of fields included in the field survey in Fairfax County. A sample constituted 15 attractive silks, except in a few instances when plots first came into silk and this number was not available.

Table 4 gives a summary of the abundance of eggs in relation to the corn acreage in attractive silk throughout the season. The same 6-day periods as those classifying the fields covered in the survey in Fairfax County (table 6) were used.

TABLE 4.—*Seasonal abundance of eggs of the corn earworm in relation to the abundance of corn attractive for oviposition, Arlington and Fairfax Counties, Va., 1936*

Period of sampling	Samples	Silks examined	Eggs found	Eggs per silk	Corn acreage in maximum silk	Numerical rating of abundance of eggs [1]	Seasonal abundance of eggs
	Number	*Number*	*Number*	*Number*	*Percent*		*Percent*
July 18–23	8	120	67	0.56	4.9	2.7	4.9
July 24–29	4	60	39	.65	23.4	15.2	27.4
July 30–Aug. 4	8	120	58	.48	25.1	12.0	21.7
Aug. 5–10	5	75	26	.35	30.5	13.8	24.9
Aug. 11–16	8	79	130	1.65	7.1	11.7	21.1
Aug. 17–22	8	120	210	1.75			
Total	41	574	530		100.0	55.4	100.0

[1] Calculated by multiplying eggs per silk by acreage in maximum silk.

The general abundance of corn earworm eggs per silk during the season at Arlington shows a trend similar to that observed at Charlottesville (table 1). When the number of eggs per silk is adjusted according to the percentage of the corn acreage attractive for oviposition, it may be seen that there is a great increase in the abundance of eggs during the second 6-day period and a slight decrease during the following periods, which probably has little significance. Of particular interest is the fact that during the period August 5–10, when the counts showed the fewest eggs per silk, the abundance of eggs was

high when adjusted according to the corn acreage in attractive silk. Moths of the second and third broods unquestionably were very abundant, even though the eggs appeared to be scarce. The great decrease in the acreage of corn attractive for oviposition during the period August 11–16 obviously resulted in a concentration of eggs per silk. Oviposition continues at a high rate in the late-maturing fields and for a longer period than on the earlier maturing corn because of the greatly diminished supply of corn in attractive silk and also

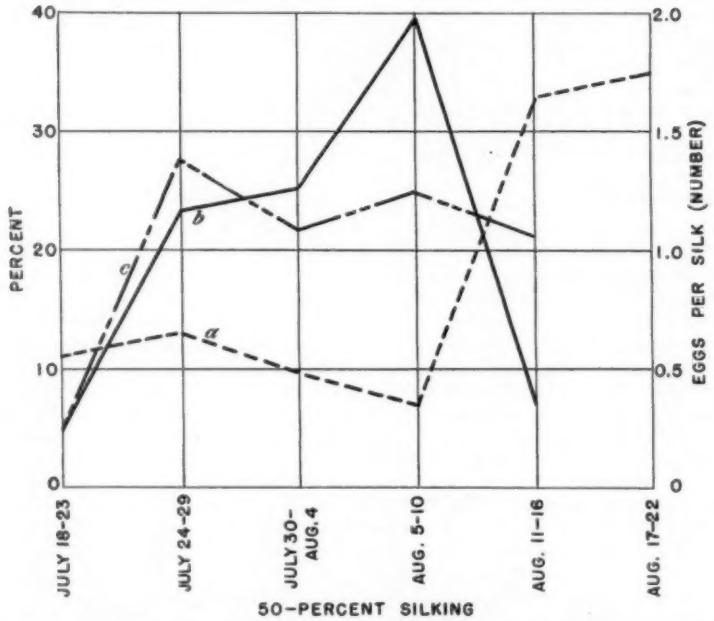

FIGURE 2.—Abundance of eggs in relation to abundance of corn in attractive silk, Arlington and Fairfax Counties, Va., 1936: *a*, Number of eggs per silk; *b*, percentage of acreage in silk; *c*, percentage of total eggs.

because of the retarded rate of maturing due to shorter days and somewhat lower temperatures late in the summer.

The relation between the number of eggs per silk and the abundance of eggs when adjusted according to the percentage of the total acreage of corn attractive for oviposition is shown graphically in figure 2. There is a positive correlation between the seasonal abundance of corn in attractive silk and the seasonal abundance of eggs. It is evident that the peak of the moth population and eggs was reached before it was indicated by the egg counts.

These data, confirming those from Charlottesville, Va. (table 1), show clearly that egg counts in themselves are not an accurate measure of the abundance of the corn earworm on corn, but must be considered in connection with the acreage of corn attractive for oviposition.

SURVEY OF SEASONAL ABUNDANCE IN FIELD CORN, 1934–37

METHODS

Since experience had shown that successive plantings of corn in small plots did not give a satisfactory measure of the seasonal abundance of the corn earworm, methods were developed in which use was made of a group of fields representing the planting period for a community. To obtain a representative sample for the area surveyed, all the fields on both sides of a route established at planting time were chosen for observation throughout the season.

In extensive studies on the egg-laying habits of the earworm moth, Phillips and Barber (*10*) found that the silks are most attractive for oviposition on the third day after emerging from the ear shoot. Consequently fields normally reach their maximum attractiveness for oviposition at about the time when the maximum amount of fresh silk is present.

In 1934, 1935, and 1936 counts were made to determine the relative maturity of the fields during the silking period. No silk counts were made in 1937, the fields being classified solely on the basis of when they began to silk, which is a more practical method, and probably as accurate as making silk counts. The larval-population counts were made by opening the ears approximately 1 month after the fields came into silk. Ears from which larvae had made their exit to enter the soil for pupation were recorded as infested with one larva. The samples were taken at random. In 1934 and 1935 5 samples of 20 ears each on consecutive culms, in 1937 10 samples of 10 ears each, and in 1936 5 samples of 40 ears each were examined from each field. In 1936 culm counts were also made, so that a better idea could be obtained of the general ear population per acre. In most of the fields the stand was thinned after it was well established, which tended to make the culm population uniform. The culms were counted in 50 feet of row length at the five points where the examinations were made to determine the infestation. With rows spaced at 3.5 feet, as found in all the fields, 250 feet of row length constitutes about one-fiftieth of an acre. Some culms bore two ears, but these were largely offset by barren culms. No multiple-eared varieties were encountered.

One difficulty in determining the seasonal abundance of the corn earworm in a survey of this type is the cannibalistic habit of the larvae, which greatly reduces the larval population in late-maturing fields where oviposition has been concentrated. The infestation counts consequently give a better index of the number of larvae that enter the soil for pupation than of the abundance of moths or eggs.

The larval population for each silking period was found by calculating the acreage in each group of fields that would be 100 percent infested if the infestation were concentrated on such acreage, and then calculating the percentage of the total acreage thus infested for each silking period.

GENERAL CONDITIONS OF THE AREA SURVEYED

In 1934 and 1935 the survey was made in Montgomery County, Md., and in 1936 and 1937 directly across the Potomac River in Fairfax County, Va. This general area has a rather irregular topography and is devoted mostly to general and dairy farming. The corn

earworm population was studied largely in field corn, although a small acreage of sweet corn was encountered. As far as could be determined, the seasonal development of the corn earworm in the two communities surveyed was comparable. The farm practices were similar, although a greater acreage of silage corn in Fairfax County accounted for an increased acreage planted late. All the corn under observation in both areas was cut. In the earliest-maturing fields cutting was begun the latter part of August, and in the late fields cutting was usually completed early in October.

SURVEYS IN MONTGOMERY COUNTY, MD., 1934 AND 1935

The data obtained from the survey in Montgomery County are summarized in table 5. The seasonal abundance of the larvae in relation to the percentage of ears infested and to the corn acreage attractive for oviposition is illustrated in figure 3. There is a slight drop in the percentage of infestation in the fields of the second group in both 1934 and 1935, but since there is a considerable increase in the acreage of corn attractive for oviposition, it is obvious that the earworm population in the area as a whole is increasing rapidly. In both years the maximum larval population occurred in the maximum acreage of corn in attractive silk. In 1935 the percentage of ears infested reached a minimum at the same time that the population of larvae when adjusted to acreage in susceptible silk reached a maximum. With the reduction of the acreage of corn in attractive silk there was also a decrease in larval population, but the percentage of ears infested increased.

TABLE 5.—*Seasonal abundance of the corn earworm in Montgomery County, Md., in 1934 and 1935 and in Fairfax County, Va., in 1936 and 1937*

MONTGOMERY COUNTY, MD.

Grouping of fields according to silking period [1]	Fields	Acreage silking		Ears infested	Range of infestation	Acreage with all ears infested	
1934	*Number*	*Acres*	*Percent*	*Percent*	*Percent*	*Acres*	*Percent*
July 9–15	2	26	9.0	25.0	24–26	6.5	7.9
July 16–22	5	72	24.8	22.0	7–37	15.8	19.1
July 23–29	11	163	56.2	29.6	11–52	48.2	58.3
July 30–Aug. 6	3	29	10.0	42.0	22–71	12.2	14.8
Total	21	290	100.0	29.2	7–71	82.7	28.5
1935							
July 14–20	5	68	19.4	24.8	15–37	16.9	16.1
July 21–27	15	160	45.7	21.3	6–34	34.1	32.5
July 28–Aug. 3	7	64	18.3	39.0	23–60	25.0	23.8
Aug. 4–10	5	58	16.6	50.0	39–68	29.0	27.6
Total	32	350	100.0	30.3	6–68	105.0	30.0

FAIRFAX COUNTY, VA.

1936							
July 18–23	3	19.0	4.9	25.9	12.0–40.5	4.9	5.3
July 24–29	10	90.5	23.4	14.9	5.0–32.5	13.5	14.5
July 30–Aug. 4	9	97.0	25.1	17.2	4.5–26.5	16.7	17.9
Aug. 5–10	13	153.0	39.5	28.9	15.5–43.0	44.2	47.4
Aug. 11–16	5	27.5	7.1	50.8	35.5–64.5	14.0	15.0
Total	40	387.0	100.0	24.8	4.5–64.5	93.3	24.1
1937							
July 5–11	3	44	12.0	36.7	30 –48	16.1	8.1
July 12–18	15	118	32.1	31.4	13 –53	37.1	18.6
July 19–25	16	145	39.4	63.3	33 –94	91.8	46.0
July 26–Aug. 1	2	16	4.3	62.0	55 –69	9.9	5.0
Aug. 2–8	2	9	2.4	96.0	93 –99	8.6	4.3
Aug. 9–15	2	13	3.5	100.0	100	13.0	6.5
Aug. 16–22	2	23	6.3	100.0	100	23.0	11.5
Total	42	368	100.0	54.8	13 –100	199.5	54.2

[1] In 1934, 1935, and 1937 these dates represent the beginning of silking, but in 1936 they represent the 50-percent silking period.

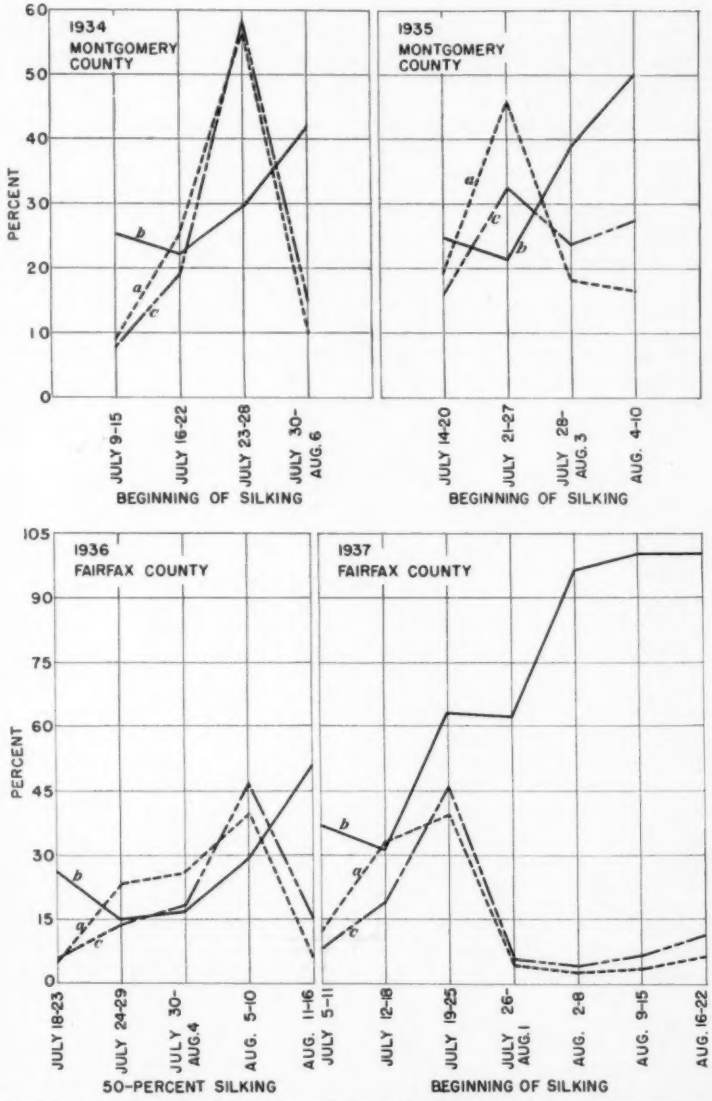

FIGURE 3.—Relation between abundance of the corn earworm and the acreage in silk in cornfields in Montgomery County, Md., in 1934 and 1935, and in Fairfax County, Va., in 1936 and 1937: *a*, Percentage of total acreage silking; *b*, percentage of ears infested; *c*, percentage of total acreage with all ears infested.

SURVEYS IN FAIRFAX COUNTY, VA., 1936 AND 1937

The survey in Fairfax County was along the same route both years, and in most instances on the same farms. The data are summarized in table 5 and figure 3. A detailed summary of the data obtained in 1936 is given in table 6.

TABLE 6.—*Detailed summary of the survey of the seasonal abundance of the corn earworm on field corn in Fairfax County, Va., 1936*

Grouping of fields according to 50-percent silking period	Size of field	Total culms in field	Ears infested		Larvae per 100 ears	Total larval population
	Acres	*Number*	*Percent*	*Number*	*Number*	*Number*
July 18–23	9	80, 550	29.0	23, 360	29.5	23, 762
	3	21, 150	40.5	8, 566	41.5	8, 777
	7	40, 250	12.0	4, 830	12.0	4, 830
Total	19	141, 950	25.9	36, 756	26.3	37, 369
July 24–29	6	33, 900	9.5	3, 221	9.5	3, 221
	7	46, 900	7.5	3, 518	7.5	3, 518
	7	47, 600	7.5	3, 570	7.5	3, 570
	3.5	23, 975	8.0	1, 918	8.0	1, 918
	6	37, 500	5.0	1, 875	5.0	1, 875
	8	54, 000	10.0	5, 400	10.0	5, 400
	8	57, 200	9.0	5, 148	9.0	5, 148
	18	134, 100	16.5	22, 127	16.5	22, 127
	18	178, 200	19.0	33, 858	19.0	33, 858
	9	59, 400	32.5	19, 305	32.5	19, 305
Total	90.5	672, 775	14.9	99, 940	14.9	99, 940
July 30–Aug. 4	7	48, 300	14.5	7, 004	14.5	7, 004
	5	41, 250	8.0	3, 300	8.0	3, 300
	25	157, 500	11.5	18, 113	11.5	18, 113
	8	48, 400	7.0	3, 388	7.0	3, 388
	4	29, 800	20.5	6, 109	20.5	6, 109
	9	59, 400	24.0	14, 256	24.0	14, 256
	6	38, 700	4.5	1, 742	4.5	1, 742
	25	158, 750	26.5	42, 069	26.5	42, 069
	8	66, 400	23.5	15, 604	23.5	15, 604
Total	97	648, 500	17.2	111, 585	17.2	111, 585
Aug. 5–10	7	50, 750	26.0	13, 195	26.0	13, 195
	6	36, 300	20.0	7, 260	20.0	7, 260
	7	53, 900	15.5	8, 355	15.5	8, 355
	12	99, 600	28.0	27, 888	28.5	28, 386
	8	56, 800	27.0	15, 336	27.0	15, 336
	12	122, 400	24.5	29, 988	24.5	29, 988
	25	233, 750	31.5	73, 631	31.5	73, 631
	18	131, 400	26.0	34, 164	26.0	34, 164
	7	53, 200	22.0	11, 704	23.0	12, 236
	9	73, 350	31.5	23, 105	31.5	23, 105
	12	138, 600	27.0	37, 422	27.0	37, 422
	20	120, 000	43.0	51, 600	43.0	51, 600
	10	86, 000	33.5	28, 810	33.5	28, 810
Total	153	1, 256, 050	28.9	362, 458	28.9	363, 488
Aug. 11–16	5	34, 500	35.5	12, 248	35.5	12, 248
	4	36, 800	57.0	20, 976	57.0	20, 976
	5	30, 250	64.5	19, 511	74.0	22, 385
	4.5	33, 975	37.0	12, 571	39.0	13, 250
	9	111, 150	54.0	60, 021	56.5	62, 800
Total	27.5	246, 675	50.8	125, 327	53.4	131, 659
Grand total	387	2, 965, 950	24.8	736, 066	25.1	744, 041

In general, the seasonal trend of the population, the percentage infestation, and the abundance of corn attractive for oviposition were similar to those of 1934 and 1935 in Montgomery County. In 1936 the decrease in the percentage infestation in the second period was

greater than in any other year. This is attributed to a low moth population, which had not had sufficient time to build up after the heavy mortality of hibernating pupae during the previous winter. Two methods of calculating the seasonal abundance were compared in 1936. There was very little difference in the results of computing the seasonal population on the basis of the acreage 100 percent infested and the larval population based on the percentage of ears infested and the culm population.

After a mild winter the corn earworm was abundant during 1937. The percentage of ears infested was higher in the earliest silking fields than in any of the other years. An extreme example of how a 100-percent infestation in late-maturing fields may obscure the abundance of the insect is illustrated in figure 3. As has been stated, cannibalism among larvae in late-maturing fields makes it difficult to ascertain the abundance of moths or eggs by counts of larvae made approximately a month after a field comes into silk. However, even if the population in late fields were a few times greater than that shown in the graph, the percentage infestation would still be a poor index of the insect's abundance in comparison with the percentage infestation in periods when the acreage of attractive corn was much greater.

DISCUSSION OF SEASONAL ABUNDANCE

The range in the percentage infestation in the various groups of fields for the 4 years is given in table 5. There is, in each group, a rather wide range in percentage of infestation. Each year the trend of the minimum percentage infestation is very similar to the trend of the maximum percentage infestation. Among the factors contributing to this wide range are variations in (1) source of moths, (2) uniformity in varieties of corn, (3) soil fertility and uniformity, (4) temperature and soil moisture, (5) attractiveness of different varieties, and (6) overlapping in maturity of fields between the periods.

That the source of moths is important in this respect is evidenced by the building up of infestations in contiguous seasonal plantings. There is considerable variation in the length of the silking period and the time required to mature in different varieties. Some fields reach their maximum silking period in 8 or 10 days, whereas others require 2 weeks. Soil fertility, temperature, and moisture are important factors in the rate of growth. Different parts of a field irregular in topography vary greatly in maturity at silking time, which results in their being exposed to different moth populations. Variation in attractiveness of different fields is very evident, and was observed between field corn and sweet corn. In grouping the fields according to maturity in weekly periods, overlapping in maturity between periods is unavoidable.

In the area adjacent to the District of Columbia the silking period begins either late in June or early in July, and attractive fresh silks are generally present until the coming of frost, usually in the latter part of October. The first corn to come into silk is a small acreage of early sweet corn on which moths emerging late from overwintering pupae the last of June and early in July, as well as the earliest moths of the second brood, concentrate for oviposition. This results in a high percentage of ear infestation. The earliest field corn, usually only a few small fields in a community, comes into silk about the second

week of July. The infestation in these fields consists primarily of the early-issuing second brood of moths and is normally lower than in fields of early sweet corn, but higher than in fields coming into silk a week later. With the rapid increase in acreage of corn in silk the percentage of ears infested declines but the general population of larvae increases. The rapid increase in the acreage of corn attractive for oviposition has the effect of dispersing the increasing moth population over a large area. As the acreage of corn attractive for oviposition decreases, the population becomes concentrated, resulting in a heavy deposition of eggs on a small late-silking acreage. The population of moths and eggs is normally about as high late in July or early in August, when superficially they appear to be reduced in numbers, as late in August and in September, when they appear to be very abundant.

The minimum infestations found in Kansas by Headlee (*7*) and McColloch (*9*) in plantings made May 1 were apparently caused by a rapidly increasing acreage of corn attractive for oviposition, and not by a scarcity of moths. Apparently both these writers overestimated the relative abundance of eggs late in August and in September. The explanation by Phillips and Barber (*10*) that corn planted in midseason (May 8–29), which silks the latter part of July, usually receives the fewest eggs because it silks between the appearance of the first and second broods of moths does not seem valid. It is obvious, from observations in northern Virginia, that moths of the second brood would normally be abundant at Charlottesville during the latter part of July, and that the comparative abundance of attractive corn is a more important factor in the relative amounts of damage in field corn planted at different dates than has been realized. The conclusion by Phillips and Barber (*12*) that in the latitude of Virginia corn should be planted on or before May 8 to reduce the earworm injury is undoubtedly correct. According to the data obtained in the vicinity of the District of Columbia, it appears certain that the greater the acreage planted early in May the lower will be the percentage of infestation in such plantings.

SEASONAL DAMAGE

Phillips and Barber (*11*) found that, at Charlottesville and Richmond, Va., field corn planted between April 30 and May 15 showed less loss in yield due to the corn earworm than corn planted later. They considered it inadvisable to plant field corn in that section after the middle of May. Since their data in regard to injury in corn planted on different dates (*11, table 4*) give some idea of the seasonal abundance of the corn earworm in the two areas, they have been adapted for this purpose in table 7 and figure 4. Table 7 shows that slightly over half of the corn acreage included in their study was planted between May 1 and 15, and that the fields planted during this period had the smallest average number of kernels injured per ear as well as the lowest percentage loss in yield by weight. By adjusting the damage according to the acreage of corn planted during the various periods, it was found that the percentage of the total loss in yield was greatest in this period. The corn planted between June 1 and 15, amounting to 7.9 percent of the total acreage under observation, had approximately 2⅓ times as many injured kernels per ear as

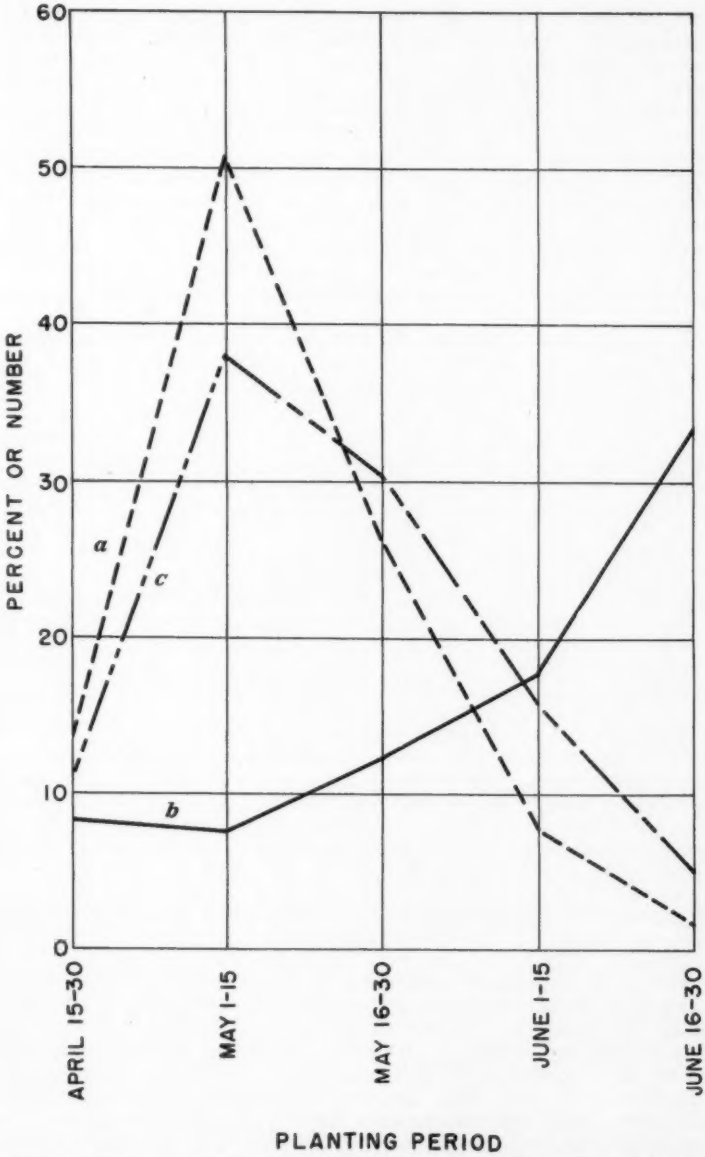

FIGURE 4.—Relation of acreage to the total loss in yield and seasonal kernel injury, Charlottesville and Richmond, Va., 1927 and 1928. (Adapted from data of Phillips and Barber (*11*)): *a*, Percentage of total acreage planted; *b*, kernels injured per ear; *c*, percentage of total loss in yield.

that planted between May 1 and 15, but the percentage of the total loss in yield by weight was less than half as much. Corn planted between June 16 and 30, 1.5 percent of the total acreage, was most severely injured, yet it bore only 5 percent of the total loss in yield by weight. Nearly 50 percent of the loss in yield occurred in the group of fields planted before May 16. The slight reduction in kernel injury in the fields planted May 1–15 under that in fields planted April 15–30 was apparently the result of a rapid increase in the acreage of corn attractive for oviposition. These data indicate that the latter part of the first brood and the second brood are of primary importance in the losses caused by the earworm. The statement by McColloch (*9*) that the first and second broods are of little importance in comparison with the third is not valid for the areas studied in Virginia.

TABLE 7.—*Seasonal injury caused by the corn earworm at Charlottesville and Richmond, Va., in 1927 and 1928*

(Adapted from Phillips and Barber (*11, table 4*))

Planting period	Approximate acreage planted	Portion of total acreage	Kernels injured per ear	Numerical rating of kernels injured [1]	Portion of total kernels injured	Reduction in yield by weight	Numerical rating of reduction in yield [2]	Portion of total loss in yield
	Acres	*Percent*	*Number*		*Percent*	*Percent*		*Percent*
April 15–30	247	13.5	8.44	113.9	11.2	1.13	15.3	10.7
May 1–15	929	50.9	7.80	397.0	39.0	1.06	54.0	37.8
May 16–30	478	26.2	12.30	315.2	31.0	1.66	43.5	30.5
June 1–15	144	7.9	17.93	141.6	13.9	2.90	22.9	16.0
June 16–30	27	1.5	33.53	50.3	4.9	4.74	7.1	5.0
Total	1,825	100.0	----------	1,018.0	100.0	----------	142.8	100.0

[1] Calculated by multiplying the percentage acreage planted by the kernels injured per ear.
[2] Calculated by multiplying the percentage acreage planted by reduction in yield by weight.

Although the loss in yield caused by the earworm in late-maturing corn is less than in the more numerous early-maturing fields, the larval population is of primary importance in contributing to the population of overwintering pupae. A large percentage of the pupae that hibernate successfully under normal winter temperatures and precipitation enter the soil from such fields the latter part of August or the early part of September.

SEASONAL ABUNDANCE OF THE CORN EARWORM IN RELATION TO CLIMATE

The study of winter survival of the corn earworm in relation to its general abundance the subsequent season was begun in the fall of 1933. Hibernation cages containing larvae collected from field corn were established early in September each year except 1934, when inclement weather delayed their establishment until late in September. Experience had shown that there was a much greater mortality among individuals going into hibernation the latter part of September than among those entering the soil early in the month. This fact was clearly brought out by examination of field plots in the spring of 1935. Survival in these plots, where larvae began entering the soil during the third week of August, was 68 percent as compared with 4 percent in

the cages. Consequently the survival of pupae in cages in the spring of 1935 is not considered comparable with that in 1934, 1936, and 1937.

The most important factors affecting winter mortality of corn earworm pupae are temperature, soil moisture, and the presence or absence of snow cover during periods of low temperature. The vital temperatures in this area are those occurring in December, January, and February. The pupae are most susceptible to below-freezing temperatures when the soil moisture is high.

The climatological data presented in table 8 are condensed from the records of the Weather Bureau station at Washington, D. C., compiled by Weeks (*14*). The effect of weather conditions on pupal survival and the abundance of the corn earworm in the subsequent season is readily seen. During the winter of 1933–34 both the temperatures and the precipitation were subnormal. The pupal survival in hibernation cages was 14 percent, and the ear infestation in 1934 was 28.5 percent. In the winter of 1934–35 temperatures and precipitation were nearly normal, data from outdoor plots indicated a higher pupal survival, and the percentage of infestation in field corn in 1935 was 30.0 percent. In the winter of 1935–36 an accumulated temperature deficiency of 13.1° F. and an excess of 3.82 inches of precipitation resulted in a pupal survival of only 1 percent and an ear infestation of 24.1 percent in 1936, the lowest for the 4 years.

The effect on hibernating pupae of low temperatures when combined with a high soil-moisture content without protection by snow cover is brought out strikingly in the data for that winter. During January heavy rains shortly before a rapid drop in temperature, which continued at a low point for approximately 1 month, caused the soil to heave severely, and when the soil settled again in the spring it embedded a large percentage of the few surviving pupae, preventing the emergence of moths. The minimum temperature recorded in soil without vegetation that winter was 22.5° F. at a depth of 4 inches.

TABLE 8.—*Relation of winter temperatures and precipitation to the spring survival of pupae and the abundance of the corn earworm on field corn the subsequent summer in the area of Maryland and Virginia adjacent to the District of Columbia*

Season	Temperature Dec. 1 to Mar. 1			Precipitation Oct. 1 to Apr. 1		Pupal survival	Abundance of corn earworm	Fields less than 30-percent infested
	Mean	Accumulated departure from mean	Days below 20° F.	Total	Accumulated departure from normal mean			
	°F.	°F.	*Number*	*Inches*	*Inches*	*Percent*	*Percent*	*Percent*
1933–34	34.0	−3.2	29	15.31	−3.79	14.0	28.5	57.1
1934–35	35.4	+.7	16	18.27	−.83	4.0	30.0	56.4
1935–36	30.7	−13.1	38	23.01	+3.82	1.0	24.1	72.5
1936–37	40.1	+14.9	1	20.35	+1.25	24.5	54.2	21.4

The mildest winter weather occurred in 1936–37, when the accumulated temperatures were 14.9° F. above normal and the precipitation was 1.25 inches above normal. This resulted in a pupal survival in cages of 24.5 percent and an ear infestation of 54.2 percent during the summer of 1937.

The most severe temperatures in any 1 month of the 4-year period were in February 1934, when the minimum temperature was −6.0° F. with a departure from the normal mean of −10.7°. The high survival of pupae in the spring of 1934 is attributed to the fact that the soil moisture was low because of a deficiency in precipitation from October 1 to April 1, and also to an adequate snow cover during the exceedingly low temperatures in February.

The importance of soil moisture as a factor in winter mortality of pupae was well brought out in outdoor insectary tests during the

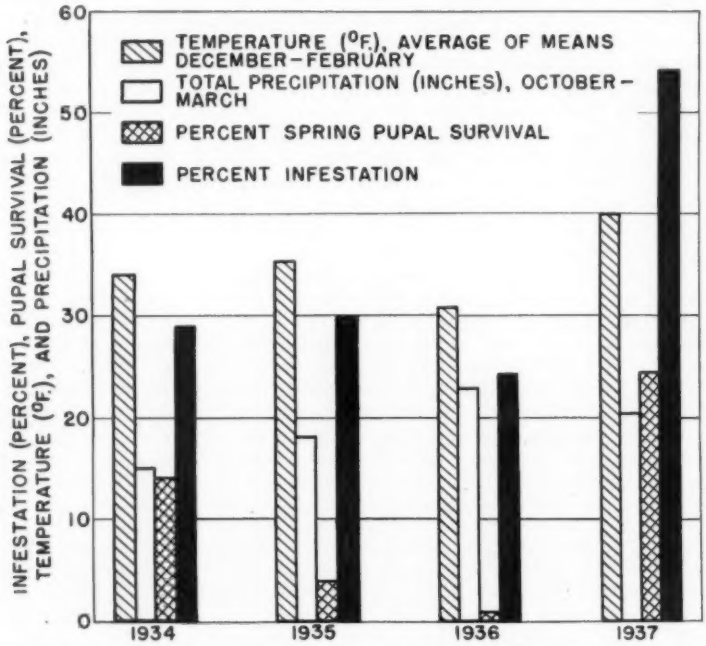

FIGURE 5.—Relation of mean temperature of December, January, and February and precipitation from October to April to spring survival of pupae and the abundance of the corn earworm the subsequent season.

winters of 1936–37 and 1937–38. These tests indicated that high percentages of the hibernating pupae can survive exposure to air temperatures as low as 14° F. if the soil is dry, whereas such low temperatures cause a high mortality if the soil is wet.

The relation of the average minimum temperature for December, January, and February and the precipitation from October 1 to April 1 to the spring survival of pupae and the percentage of earworm infestation the subsequent season is plotted in figure 5. There is a striking positive correlation between the average mean temperatures for the 3-month period indicated and the percentage of earworm infestation the following season. Except for 1935, when the results of the survival in hibernation cages were not considered comparable for reasons already explained, there is a positive correlation between the extent of

pupal survival and the average mean temperature for the 3 winter months.

A high percentage of soil moisture contributes substantially to pupal mortality when not in combination with low temperatures. The prepupae and the newly-formed pupae are particularly susceptible in wet soil. Disease organisms, especially entomogenous fungi, are more numerous and effective in soils high in humus content, and if the soil is not too acid the common species of earthworms are abundant. Heavy rains bring the earthworms to the surface, where they invade the pupal burrows, and many earworm pupae become embedded in their castings. Not only is there a high mortality among pupae thus embedded, but the breaking down of the burrows prevents many moths from escaping to the surface.

The data obtained in this study indicate that when the mean temperature for December, January, and February is about 35° F. and precipitation is normal, the corn earworm will be sufficiently abundant to cause material damage to the corn crop. It appears safe to predict that when, with normal precipitation, the mean temperature for December, January, and February drops to 30° or below, the abundance of the corn earworm the following season will be considerably below normal.

SUMMARY

A study has been made of the general seasonal abundance of the corn earworm (*Heliothis armigera* (Hbn.)) in central Virginia and in the area in Virginia and Maryland adjacent to the District of Columbia, and also of the climatic factors that influence the seasonal abundance from year to year. This study has been made not only in experimental plantings but also by surveys of populations in cornfields.

At Charlottesville, Va., in 1932, the maximum number of eggs per silk in separated seasonal plantings of sweet corn was found in September, the minimum number in August, and the number between these extremes in the latter part of July. The percentage of ears infested by larvae in these plantings showed a similar trend. The number of eggs per silk and the percentage of ear infestation were at a minimum when general observations indicated that field corn attractive for oviposition was at its peak.

In 1934 and 1935 the percentage of infestation in seasonal plantings of sweet corn in a single block at Arlington, Va., showed a trend similar to that observed at Charlottesville. The infestations were much higher than those found in a field survey. This condition is attributed to a concentration of ovipositional activity on contiguous early-silking plots and a building up of an infestation in the later silking plots by succeeding generations. Such seasonal plantings are consequently not considered to give a satisfactory index of the general seasonal abundance of the corn earworm.

In 1936 at Arlington the number of eggs per silk was at a minimum when the acreage of corn in silk attractive for oviposition was at its maximum. When adjusted to the acreage attractive for oviposition, the population of eggs was near its height at the same time that the acreage of corn most attractive for oviposition was at its maximum. The data of 1936 indicate that the moth population reached its maximum the latter part of August, and that the heavy infestation on late-

maturing corn was the result of a concentration of oviposition on a rapidly declining acreage of attractive corn while the population of moths was still high.

In northern Virginia the corn earworm hibernates in the pupal stage more or less successfully. Emergence of moths from overwintering pupae begins the latter part of May and continues until about July 15. The first eggs are usually found the last of May. Moths of the second brood begin to appear the first week of July. Because of this overlapping of generations the number of generations can only be estimated. There are probably two complete generations and in normal seasons a considerable part of a third generation.

Most of the pupae that are to overwinter successfully become established in the soil between the middle of August and the middle of September; therefore larvae developing from eggs deposited after the first week of September are of little significance in providing overwintering populations in this area.

In surveys of field corn in Montgomery County, Md., and in Fairfax County, Va., during the period 1934–37 the percentage of ears infested was not an accurate measure of the seasonal abundance of the corn earworm. The slightly higher percentage of infestation in the few early-silking fields was due to a concentration of oviposition by the available moth population on such corn. With the rapid increase in corn acreage attractive for oviposition, the percentage of infestation receded slightly, although the population was actually increasing rapidly. The larval population reached its maximum about the time when corn in fresh silk was at its maximum. The highest percentage of infestation occurred in the relatively small acreage of late-maturing corn and was due to concentration of ovipositional activity. Cannibalism causes a heavy larval mortality in late-maturing corn and reduces the accuracy of egg and moth population determinations in such corn about 30 days after it has begun to silk. The method used to determine seasonal abundance consequently gives an index of the number of larvae entering the soil for pupation. The best method of determining the seasonal abundance of moths is to adjust the egg population per silk according to the amount of corn in silk attractive for oviposition.

In a study of the seasonal damage caused by the corn earworm Phillips and Barber (*11*), found that the percentage of loss by weight was lightest in corn planted before May 16. The corn planted during this period accounted for about two-thirds of the total acreage and about half of the total loss in yield. This analysis showed that the loss in yield in the small acreage of late-planted corn is of minor importance. The late-planted fields are of major importance in providing overwintering pupae. The recommendation that corn be planted as early as compatible with obtaining a satisfactory stand has further justification because the greater the acreage planted at such time, the lower is likely to be the percentage of ears infested.

During the period 1934–37 there was a positive correlation between the average mean temperature for December, January, and February, the rate of survival of overwintering pupae, and the abundance of the corn earworm in field corn the following season. In 1936 low temperatures and high soil moisture with inadequate snow cover resulted in a heavy mortality of hibernating pupae and the lowest

population for the 4-year period. In an open insectary a high percentage of pupae survived an exposure to 14° F. on dry soil, whereas a heavy mortality followed this exposure on moist soil. In the area studied, when winter temperatures and precipitation are normal there is sufficient survival to cause material damage to the corn crop in the subsequent season. When the mean winter temperature falls to 30° F. or below, a reduction in the abundance of the corn earworm in the field may be expected.

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YELLOW DWARF OF POTATO IN WISCONSIN [1]

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INTRODUCTION

During the growing seasons of 1930, 1931, and 1932 heavy losses from disease were sustained in the potato crop in central Wisconsin, particularly in Portage, Waupaca, and Waushara Counties. One of the outstanding characteristics of those epidemics was the general prevalence of poor stands from apparently sound tubers. Investigations beginning in 1933 have shown that the yellow dwarf virus was the primary cause of the difficulty. In 1935 the disease was destructive in Washington County, in the southeastern part of the State, many fields there being close to a total loss. In 1937 it was more widely prevalent and destructive in Wisconsin than in any year on record, being common not only in central Wisconsin but throughout the eastern part of the State, particularly in Outagamie, Fond du Lac, and Washington Counties. This paper is a report of field and greenhouse studies of the disease which have been under way during the period from 1933 to 1938, inclusive.

SYMPTOMS OF YELLOW DWARF IN WISCONSIN

In general the symptoms of the disease in Wisconsin coincide with the first description by Barrus and Chupp (*1*)[2] from New York and with that by Muncie (*7*) from Michigan. Certain differences prevail, however, which may be expected under the influence of environment. Goss and Peltier (*3*) showed that in greenhouse-grown plants infected with the yellow dwarf virus severe disease development occurred at 25° C., while at 15° there was only very slight internal necrosis of the tubers and no foliage symptoms. In central and southern Wisconsin the disease appears on the early-planted crop in late May or early June. In the main crop, which is planted from May 25 to June 20, the disease is commonly seen on young shoots soon after emergence.

SECONDARY TOP SYMPTOMS

The secondary symptons on the foliage, i. e., those on plants from infected seed pieces, are the most striking. In a favorable environment the shoots remain dwarfed and the internodes shortened. The leaflet margins roll upward while the long axis of the leaflet curves downward, particularly at the apex. Thus the plant is often reduced to a rosette (fig. 1, *B*). Both stem and leaves take on a yellow cast while the upper surface of the latter becomes slightly rugose. The change in color is often evident first at the growing tip of the plant (fig. 1, *C* and *D*), but it may come on almost simultaneously over the

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[2] Italic numbers in parentheses refer to Literature Cited, p. 279.

entire plant if infection has come from a diseased seed piece. Secondarily infected plants usually produce only small misshapen tubers, commonly on short stolons. Prompt dieback from the tip has been described by Barrus and Chupp (*1*) and by Muncie (*7*). This does not necessarily follow under Wisconsin conditions, at least not promptly. Some infected plants die within a few days to 2 weeks after emergence; many survive for longer periods. The course of the disease at this stage is influenced by temperature and moisture. High temperature and low humidity tend to hasten the death of infected plants.

Occasional plants assume a rosette appearance early without any marked change from normal color. They remain stunted throughout the growing season but with little or no top necrosis. These symptoms, which are referred to tentatively as "green dwarf," are commonly found in fields where typical yellow dwarf symptoms occur. Whether or not they represent a phase of yellow dwarf or a distinct disease has not been determined.

Pith necrosis of stems is a common feature. It appears shortly after chlorosis of the foliage and, beginning near the growing tip, may eventually extend the entire length of the main stem. It may or may not be most severe at the nodes. As yellow dwarf plants become weakened, the vascular system of the lower portion of the stem may turn brown and the fibrous roots become discolored and shriveled. At this stage the disease may readily be confused with certain stages of one or another of the fusarium wilts. In all probability secondary soil organisms are contributing causes to these symptoms through their invasion of the root system of plants weakened by yellow dwarf.

Often the most common secondary symptom of yellow dwarf under central-Wisconsin conditions is failure of the infected seed piece to produce an emerging plant. In warm soil many seed pieces do not germinate at all; others produce shoots that die before they reach the surface. When environmental conditions are such as to favor nonemergence the lack of stand is a much more striking sign of the disease than the symptoms on the small percentage of infected plants which emerge. Infected seed pieces from emerging and nonemerging hills are commonly hard and glassy in texture. They usually remain intact without decay until late in the growing season or until harvest.

The symptoms discussed up to this point are those that appear promptly on plants from infected seed pieces under favorable environment. In some cases delayed secondary symptoms appear under the same environmental conditions and ordinarily they are not distinguishable from primary symptoms resulting from spread during the current season. By making experimental plantings on the tuber-unit basis, usually with three hills from each seed tuber, late secondary symptoms have been distinguished from primary symptoms by the fact that the three hills in a given unit usually succumb simultaneously in the case of the former type, while in the latter type the symptoms are not correlated with hill units. Even under conditions favorable for disease expression the first appearance of the delayed symptoms may be 6 weeks or more after emergence, and often after the plants have grown quite normally to nearly maximum height. In fact, there is reason to believe that some plants infected from diseased seed pieces fail to show symptoms during the entire second season.

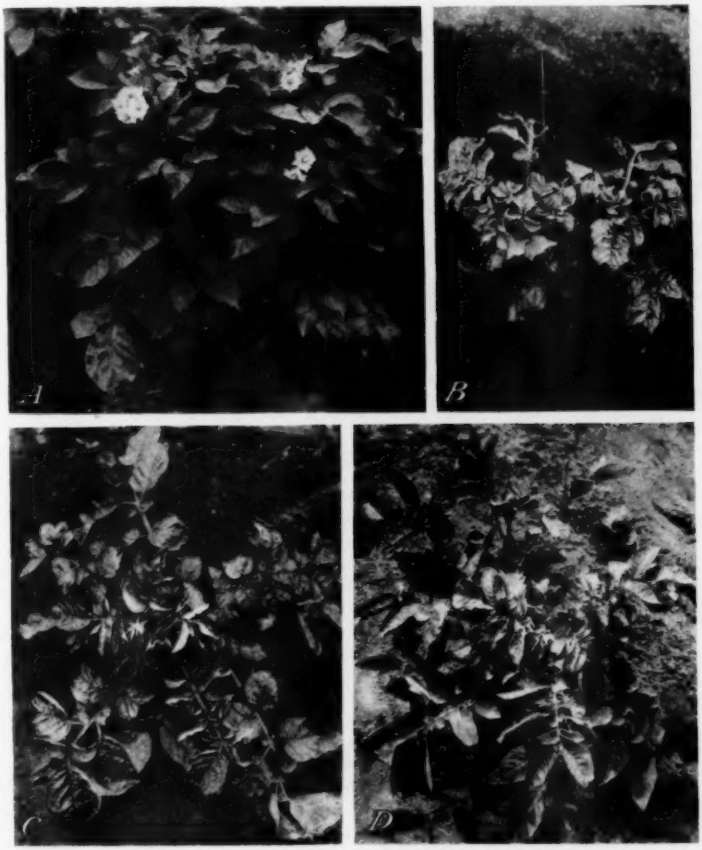

FIGURE 1.—Secondary top symptoms of yellow dwarf on potato plants. All are of the same age and grew in the same field of Irish Cobbler variety planted in the latter part of April 1938, in central Wisconsin; photographed July 7. *A*, Healthy plant. *B*, Plant that became dwarfed early, most of the leaflets showing rugosity, upward roll of margins, and downward curve of the longitudinal axis. *C*, Plant in which several leaves developed to normal size before acute symptoms appeared in the youngest leaves. Rugosity and slight marginal roll in the older leaves are noticeable when comparison is made with healthy plant in *A*. *D*, Plant that grew normally for a still longer period than the one in *C* before secondary symptoms began to appear in the youngest leaves, where the leaflet margins are beginning to roll upward while the downward longitudinal curving has just been initiated. It will be seen that the leaflets of most of the lower leaves are normal as to size, margin, and smoothness of lamina when compared with the healthy plant, *A*. Blossoming in all diseased plants is noticeably suppressed.

The first signs are slight chlorosis and marginal upward rolling of leaflets near the growing tip, and in this respect they are not unlike primary symptoms in appearance. Usually, however, chlorosis of the entire plant comes on more promptly than after primary infection and, in the main, all shoots from an infected seed piece show the symptoms simultaneously. Occasionally a healthy and an infected shoot arise from the same seed piece. Such healthy-appearing shoots commonly develop delayed symptoms; rarely do they remain healthy in appearance until harvest. When seed tubers are cut and planted on the hill-unit basis occasional cases arise in which one hill of a unit remains healthy and produces tubers free from yellow dwarf while the others produce diseased plants and tubers. Quite as often as not the stem-end piece of a unit produces a healthy hill while the bud-end pieces of the same tuber produce diseased hills. This indicates that as the virus progresses through the stolon it does not necessarily affect the nearest eyes and may become distributed irregularly in the tissues.

PRIMARY TOP SYMPTOMS

The primary symptoms on foliage arising from current-season dissemination of the virus appear as chlorosis and upward roll of leaflets in the vicinity of the growing point. Symptoms of the disease develop progressively downward and pith necrosis, appearing first at the tip, follows down the stem. Often only a single shoot of a hill is affected and symptoms in the tuber are usually confined, in such a case, to those arising from the diseased shoot. It has been definitely established by study of clonal progenies from selected hills that many plants become infected, presumably late in the growing season, and produce tubers infected with the virus, although they show signs of the disease on neither tops nor tubers.

TUBER SYMPTOMS

The effect of yellow dwarf on the tubers varies widely. Early-diseased plants commonly produce small misshapen tubers, which in cross section show small necrotic areas usually scattered throughout the pith and internal phloem. Tubers from plants showing primary symptoms or delayed secondary symptoms are reduced in size and are necrotic internally. Growth cracks are common, but, as they result from many other causes, they should not be considered as a diagnostic character of yellow dwarf. Internal necrosis of tubers affected with yellow dwarf is not typically a net necrosis and should not be confused with the latter type of internal discoloration. Since the yellow dwarf necrosis occurs very commonly on the same soils and in the same regions in Wisconsin as the nonparasitic internal brown spot or sprain, the two types of tuber necrosis may be easily confused. In fact, where symptoms of the latter disease are diffused and scattered in the tissue, the two cannot be distinguished in the tuber (fig. 2.).

Unlike the potato leaf roll disease, in which necrosis is confined to the phloem, the necrotic tissue in stems and tubers of yellow-dwarf plants may be found in the pith, the inner phloem, and to some extent in the outer phloem and in the cortex. Xylem elements are seldom affected. In sections of fresh tissue the discolored areas appear as groups of disorganized cells in which has accumulated

amorphous, amber-colored material. The latter stains heavily in fixed sections when coal-tar dyes or haematoxylin are applied.

SUMMARY OF DIAGNOSTIC FEATURES

In view of the various symptoms of yellow dwarf that overlap those of other potato diseases it is obvious that no single one can serve as an infallible guide for diagnosis of this disease. This is particularly true under environmental conditions in which full expression is prevented and the disease is partially masked. Under favorable conditions the stunting, the upward marginal roll and the downward curving along the longitudinal axes of the leaflets, the chlorosis beginning at the growing tips followed by pith necrosis of the stem,

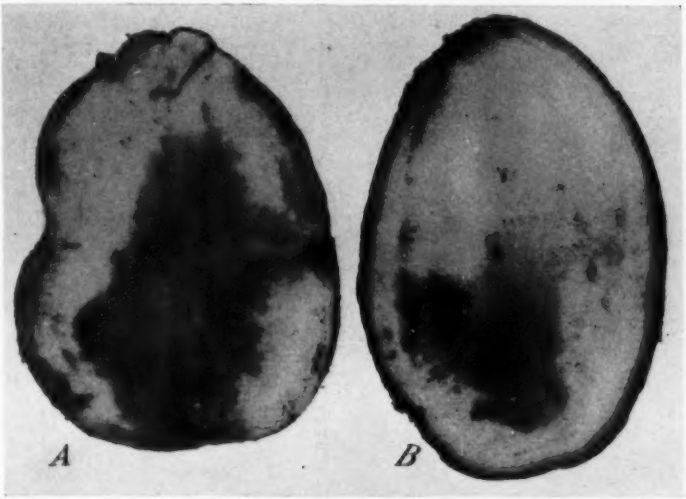

FIGURE 2.—*A*, Symptoms of yellow dwarf in potato tuber; necrosis occurs in small areas throughout the pith and internal phloem. *B*, Internal brown spot or sprain. This disease occurs commonly in tubers grown on sandy soils in central Wisconsin, is very similar to yellow dwarf, and sometimes is indistinguishable from it.

and the malformation and necrosis of the tubers, taken together, afford a very satisfactory basis for differentiation of yellow dwarf from other maladies. It should be emphasized, however, that, particularly in late-season spread, infected plants may mature with no signs of the disease either on top or tuber.

RELATION OF YELLOW DWARF TO POOR STAND

Inasmuch as the yellow dwarf epidemics in central Wisconsin in 1931 and 1932 were characterized primarily by lack of stand, a study was made in 1933, 1934, and 1935 of the relation of nonemergence to yellow dwarf.

In 1935, 15 lots of tubers designated as group 1, were taken from the field run of the poor-stand area of 1932; 8 lots (group 2) were

taken from fields of relatively good stand on the fringe of the poor-stand areas; 7 lots of tubers (group 3) were from certified fields of northern Wisconsin. Forty tubers from each lot were planted—20 on June 6, and 20 on June 23—at Almond, Portage County, in the region where disease losses had previously been very heavy. The tubers were cut into three seed pieces each, the stem-end half of the tuber being cut first and the bud half divided into the second and third pieces. These were planted consecutively in units of three hills per tuber.

TABLE 1.—*Occurrence of nonemerging hills and hills with plants showing secondary symptoms of yellow dwarf in planting made in 1933 from various seed-tuber lots at Almond, Portage County, Wis.*

Source of seed lots	Lot No.	Planting on June 6		Planting on June 23	
		Nonemerging hills	Hills showing yellow dwarf	Nonemerging hills	Hills showing yellow dwarf
		Percent	*Percent*	*Percent*	*Percent*
Group 1.—Lots from the field run of fields in the poor-stand area of 1932.	1	87	3	85	3
	2	81	2	77	6
	3	74	3	78	3
	4	49	3	77	6
	5	48	5	62	3
	6	44	3	41	4
	7	37	3	49	3
	8	33	2	39	1
	9	28	3	37	1
	10	27	2	28	3
	11	15	6	33	4
	12	15	0	14	3
	13	15	6	16	4
	14	13	0	20	3
	15	2	2	9	0
Average	1–15	38	3	44	3
Group 2.—Lots from good fields on the fringe of the poor-stand area in 1932.	16	23	0	20	0
	17	6	0	4	0
	18	5	0	3	0
	19	5	0	3	0
	20	3	0	7	0
	21	3	0	20	0
	22	1	0	14	0
	23	0	0	3	0
Average	16–23	6	0	9	0
Group 3.—Lots from certified fields of northern Wisconsin.	24	3	0	2	0
	25	1	0	2	0
	26	1	0	3	0
	27	1	0	2	0
	28	1	0	2	0
	29	0	0	0	0
	30	0	0	0	0
Average	24–30	1	0	1	0

The final data from the 1933 plot are recorded in table 1. The lots in group 1, coming from the heavily diseased area of 1932, plants generally failed to emerge in a high percentage of the hills. With the exception of lot 15, in which the stand was good, missing hills ranged from 13 to 87 percent. In the entire group 38 percent were missing in the first planting and 44 percent in the second planting. The percentage of plants showing secondary yellow dwarf symptoms was consistently low. In no case did more than 6 percent of the hills contain plants showing the disease, while the total for group 1

was 3 percent of diseased plants in each of the plantings. In group 2 no plants were observed showing secondary yellow dwarf. The missing hills were usually few in number, and the percentage for the group as a whole was much less than in group 1. In the lots from certified seed the stand was excellent and no yellow dwarf was observed. A view of this plot is given in figure 3.

The close association of severe losses due to poor stand and the occurrence of secondary yellow dwarf evident in group 1 was still more striking when individual tuber units were studied. In general, yellow dwarf hills occurred most commonly in units with missing hills. Many yellow dwarf plants died soon after emergence and by mid-

FIGURE 3.—The effect of yellow dwarf upon stand. View of the 1933 experimental plot at Almond, Wis., in which seed tubers from various sources were compared. In the center are two rows planted with seed from a yellow dwarf field of 1932 from which a very low percentage of emergence was secured. At the right are two rows from certified seed from northern Wisconsin, which yielded a 98-percent stand.

season the percentage of missing hills in group 1 had increased considerably. The occurrence of units with two missing hills and one yellow dwarf hill, or one missing hill and two yellow dwarf hills was the usual case. In groups 2 and 3, on the other hand, the missing hills were scattered irregularly, usually singly in a unit of three hills.

Hills which appeared to remain healthy throughout the season were selected from four lots in group 1, one lot in group 2, and seven lots in group 3. These were planted in 1934 in two locations—at Madison on May 28 and at Almond on June 11. Seed tubers from certified fields in northern Wisconsin were included in each planting. The plantings at the two locations yielded closely similar results. The lots from group 1 and 2 are treated collectively in the data in table 2. It is quite evident that the virus had been transmitted to many of the

hills in the previous season too late to have caused symptoms of yellow dwarf. The percentage of yellow dwarf plants averaged higher than in the parent lots in 1933. The percentage of missing hills, though not as high as in 1933, was nevertheless of the same relative order. In the five lots from group 3 of 1933 (table 1) some contamination by the virus had occurred, since the percentage of disease had increased from none in 1933 to 2 and 4 percent at Almond and Madison, respectively, in 1934, and the loss in stand increased slightly over that of 1933.

TABLE 2.—*Occurrence of nonemerging hills and hills with plants showing secondary symptoms of yellow dwarf in 1934 planting at Almond, Portage County, and at Madison, Wis., from healthy-appearing plants at Almond in 1933*

1933 lot No.	1934 lot No.	Planting at Almond, June 11		Planting at Madison, May 28	
		Non-emerging hills	Hills showing yellow dwarf	Non-emerging hills	Hills showing yellow dwarf
		Percent	*Percent*	*Percent*	*Percent*
4	1	20	7	27	10
5	2	32	13	45	2
7	3	13	12	12	10
11	4	33	7	27	7
22	5	23	3	8	12
Average lots	1–5	24	8	24	8
24	6	10	8	2	3
26	7	6	3	7	2
27	8	0	1	8	0
29	9	3	0	2	0
30	10	6	1	3	13
Average lots	6–10	5	2	4	4
Certified seed tubers from northern Wisconsin		1	1	2	0
Seed tubers from yellow dwarf hills of 1933		53	17		

In the process of selecting apparently healthy hills in rows of group 1 and group 3 in 1933 it was obvious that more of the former selected at random carried the virus than did the latter. This cannot be explained satisfactorily on the basis of the hills in group 1 being exposed more openly to nearby yellow dwarf plants than were those in group 3, since the various lots were placed in randomized order in the plot of 1933. From this and the cases studied subsequently it is suggested that some plants carry the virus through the second season without showing symptoms. A lot exposed to a heavy infestation may possibly produce more symptomless carriers at the end of the next season than a less heavily infected lot. This point deserves further study.

Tubers from representative healthy hills were selected in the autumn of 1934 from lots No. 7 and 11 (table 2) at both Almond and Madison. These were planted at Almond on June 5, 1935. The general result was that there were very few missing hills. On the other hand, a much larger percentage of yellow dwarf plants was noted than in 1933 and 1934. During the growing seasons of 1934 and 1935 continuous records of air temperature were kept. In 1933 and 1934 the air temperature was above normal in June while in 1935 it was somewhat below normal. In table 3 the summary of nonemergence and

yellow dwarf for the three seasons is given, as well as the bihourly mean of the air temperature for the 21-day period after planting in the last two seasons. It is to be seen that the average temperature was approximately 7° C. lower in 1935 than in 1934. It is also to be noted that the totals of missing hills and yellow dwarf hills in each year are close to one another. In the cool year the percentage of nonemergence was low and that of yellow dwarf symptoms was high, while in the warm year the opposite was true.

The close correlation of poor stand with yellow dwarf symptoms during the field studies of 1933, 1934, and 1935 pointed definitely to the probability that they were phases of the same disease. It was also indicated that environment played an important part in determining which phase of the disease predominated. Further studies were therefore directed toward the relation of environment to the expression of yellow dwarf symptoms.

TABLE 3.—*Comparison of relative amounts of nonemergence and secondary yellow dwarf hills at Almond, Wis., during 1933, 1934, and 1935*

Year	Mean temperature [1]	Hills planted	Missing hills	Yellow dwarf hills
	° *C.*	*Number*	*Percent*	*Percent*
1933		3,600	41	3
1934	22.8	600	24	8
1935	16.0	653	1	29

[1] Bihourly mean of air temperature for a period of 21 days after planting.

RELATION OF ENVIRONMENT TO YELLOW DWARF

FIELD EXPERIMENTS

In 1933 a quantity of tubers was collected from yellow dwarf hills in the plot at Almond. In 1934 some were planted at Madison in the southern part of the State, some were planted at Almond in the central part, and the remainder were planted at Ashland in the northernmost part. These locations were selected to provide as wide a range of temperature conditions during the growing season as might be secured within the State. Two plantings were made at each location, the first on or about May 15, the second about June 1. The differences between the results of the two plantings in any given area were not great. They are therefore combined for each location in table 4. As the season progressed the spread between the temperatures at Madison and Almond was not large; the Ashland area was decidedly cooler. In the first two locations, where temperatures were relatively high following planting, the percentage of missing hills was high and that of yellow dwarf comparatively low. In the northern location more than 90 percent of the plants emerged and nearly 50 percent showed symptoms of yellow dwarf. As in the case of the results already shown in table 3, it was evident that in the northern location where lower temperatures prevailed a greater percentage of plants emerged. The temperature was relatively high following planting at both Almond and Madison and there was little difference between results from these locations.

TABLE 4.—*Comparison of emergence and yellow dwarf in southern, central, and northern Wisconsin, 1934*

Station	Relative location in Wisconsin	Total hills	Non-emerging hills	Yellow dwarf hills
		Number	*Percent*	*Percent*
Madison	Southern	48	52	21
Almond	Central	48	46	21
Ashland	Northern	47	9	49

GREENHOUSE EXPERIMENTS

The study of the relation of air and soil temperature to the disease was continued under controlled conditions in the greenhouse. Seed tubers were selected from yellow dwarf-infected hills in the field and stored until they had passed the dormant period. In preparation for the experiments each tuber was divided into a sufficient number of seed pieces to provide a single piece for each of the air or soil temperatures being studied in a given series. Air-temperature studies were carried out in 10-inch clay pots placed in a series of greenhouses in which the temperature was kept very uniformly at 16°, 20°, 24°, and 28° C., respectively. In these cases the temperature of the soil was usually 2° to 3° lower than that of the surrounding air, owing to the cooling effect of evaporation of water from the pots. Soil-temperature studies were conducted in Wisconsin soil-temperature tanks, which were regulated to maintain the soil at 16°, 20°, 24°, and 28°, respectively. The plants growing in cans inserted in the temperature tanks were subjected to a common air temperature which fluctuated from 20° to 24°. In all cases control pots planted with seed pieces from known healthy stock were included.

AIR-TEMPERATURE STUDIES

The results of two experiments are reported in table 5. The first of these was conducted in the winter of 1934–35 and the second in the winter of 1935–36. There were uniformly good germination and growth in the controls in both cases and the data are, therefore, not included in the table. In the first experiment all seed pieces germinated; in the second there was a reduction of stand at the two highest temperatures. At 16° C. it was not possible to distinguish between plants from diseased and healthy seed pieces. When they were split longitudinally slight necrosis in the pith was noted in a small percentage of plants from diseased seed tubers. Slight external symptoms occurred at 20° and a few plants showed faint flecking in the pith. There was a marked contrast between the behavior of the plants grown at 24° and those grown at 20°, for symptoms occurred on most plants and internal pith necrosis occurred in all at the former temperature. The occurrence of pronounced external and internal signs of all plants which emerged at 28° showed that the clones were all infected by the virus. Since it may be expected that the plants growing at the lower temperatures had been infected in most instances, the suppression of symptoms was nearly complete up to 20°. These results are in general accord with those of Goss and Peltier (*3*).

TABLE 5.—*Effect of air temperature on development of yellow dwarf*

Experiment No.	Duration of experiment	Air temperature	Seed pieces planted	Non-germinating seed pieces	Plants showing external symptoms	Plants showing pith necrosis
		°C.	Number	Percent	Percent	Percent
1	Dec. 15, 1934, to Feb. 5, 1935, 52 days	16	20	0	0	10
		20	20	0	10	15
		24	20	0	85	100
		28	20	0	100	100
2	Feb. 3 to Mar. 21, 1936, 47 days	16	20	0	0	5
		20	20	0	5	15
		24	20	5	90	100
		28	20	25	100	100

SOIL-TEMPERATURE STUDIES

Several experiments were conducted at controlled constant soil temperatures during the winter periods of 1934–35 and 1935–36. As already indicated, the soil remperatures were held at 16°, 20°, 24°, and 28° C., while the air temperature fluctuated from 20° to 24°. The duration of each experiment was from 6 to 7 weeks. Control pots of healthy stock of the same variety as that of the diseased tubers were always included. Complete germination and consequent healthy plants were secured uniformly in the controls. The data from plantings of diseased tubers are summarized in table 6.

TABLE 6.—*Effect of various soil temperatures upon the emergence of plants grown from yellow dwarf-infected seed pieces of several varieties*

Variety	16° C.		20° C.		24° C.		28° C.	
	Seed pieces planted	Plants emerged	Seed pieces planted	Plants emerged	Seed pieces planted	Plants emerged	Seed pieces planted	Plants emerged
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Early Ohio	24	88	24	67	24	54	24	0
Irish Cobbler	18	100	18	72	18	11	18	6
Russet Rural	12	100	12	92	12	58	12	0
Rural New Yorker	18	83	18	61	18	6	18	6
Katahdin	36	100	36	86	36	58	36	0
Total	108	94	108	76	108	41	108	2

The trend of results was the same in each of the 5 varieties. There was a progressive decline in stand with increase in temperature. At 24° C. the average reduction was more than 50 percent while at 28° only 2 out of 108 seed pieces produced emerging shoots. These results agree with the field observations already reported, which indicated that high soil temperatures tended to reduce the stand and that nonemergence may be an important phase of the yellow dwarf disease. The proof of this contention is provided in this series of experiments, wherein a seed piece from each tuber clone was grown at each soil temperature. There is therefore no question that most, if not all, of the plants which emerged at the low temperatures were infected. Further demonstration of the fact that missing hills in yellow dwarf fields are usually the result of response to high soil-temperature effects on infected seed pieces was made in 1937. A large

number of such hills were dug 4 to 6 weeks after planting and generally the seed pieces were found to be about as turgid and free from decay as when they were planted. Many of these were collected and removed to the greenhouse where they were planted in soil held at 14° to 16° C. Practically all of them produced shoots that appeared to be quite as normal at this temperature as those from tubers of healthy stock that had been held over in storage from the previous autumn. When the temperature was increased to 24° yellow dwarf symptoms developed.

The influence of the various soil temperatures upon the occurrence of the disease in the tops is of interest. As already stated, the tops grown from tubers at the various soil temperatures were exposed to a common air temperature fluctuating from 20° to 24° C. From the results in the air-temperature series (table 5) this is an intermediate position between the most favorable air temperature for rapid disease development and that at which external symptoms are suppressed. A fully representative condition of the tops at the end of the experiments is shown in figures 4 and 5, which illustrate the Early Ohio and Russet Rural series, respectively, at the end of the experiments. The plants that emerged in 24° soil all remained dwarfed and showed symptoms promptly and decidedly. The air temperature was thus favorable in this case. In 20° soil the plants were somewhat dwarfed as compared with the controls at the same temperature, but there was clearly a decided depressive effect upon symptom development. In 16° soil there was no evidence of disease and the size of diseased and control plants was very nearly the same at the end of the experiments.

The soil-temperature series show that, whereas increase in soil temperature in which yellow dwarf-infected tubers are planted tends to reduce the percentage of emergence, decrease in soil temperature not only encourages emergence but it also tends to retard the development of top symptoms. It may be expected, therefore, that in areas with relatively cool growing seasons the field appearance of yellow dwarf would be less pronounced than in warmer regions. Slower development of secondary symptoms would be more common, while the masking of their appearance as well as those of primary infection would be greatly enhanced. Nonemerging hills would be less prevalent.

EPIDEMIOLOGY OF YELLOW DWARF

The incidence of this virus disease of potato has been extremely sporadic. While no season since 1933, when it was first distinguished in Wisconsin, has passed without its appearance in the central part of the State, its destructiveness has varied greatly from year to year. Where seed tubers from severely diseased fields of 1932 were used in 1933, losses were commonly heavy. In 1934 losses were much less severe and in 1935 and 1936 the stands were good and the percentage of diseased plants was relatively low. This period of 3 consecutive years with declining incidence of disease led to a return to the common practice of using locally grown seed in central Wisconsin. In 1937 another severe epidemic occurred which extended through the eastern half of Portage County in an eastern to southeastern direction as far as Washington County near Milwaukee. The nature of the disease

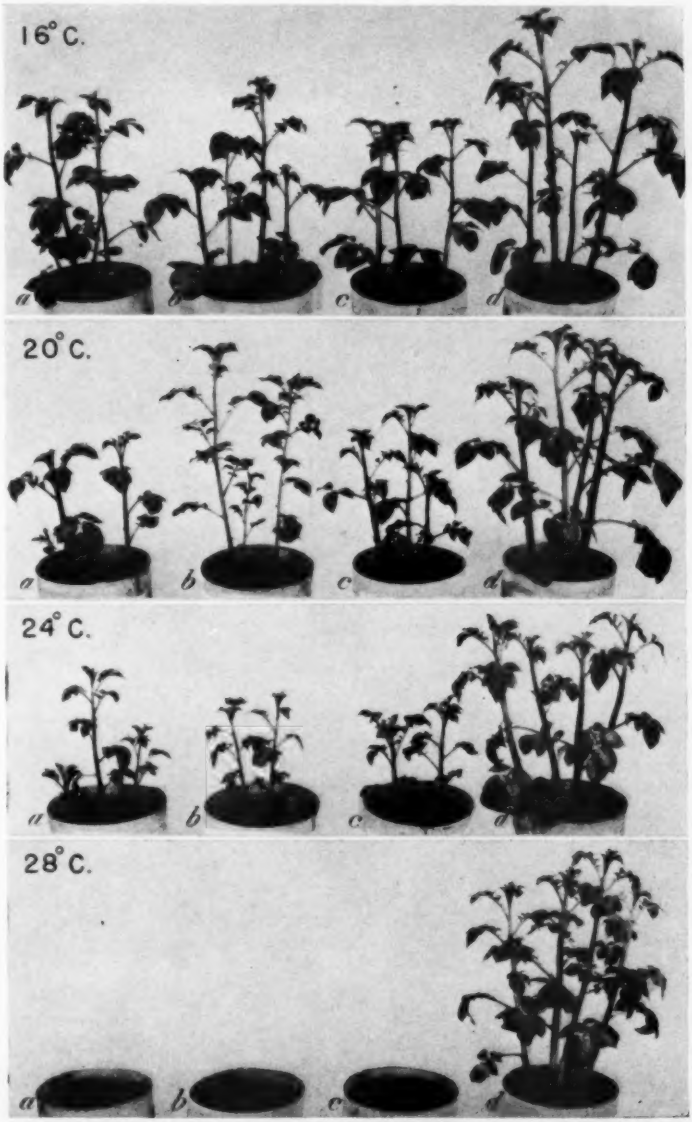

FIGURE 4.—Representative cans from the soil-temperature study with healthy (*d*) and yellow dwarf-infected seed tubers (*a* to *c*) of the Early Ohio variety. Each tuber used was divided equally between the four soil temperatures. Note reduction in stand at 24° and 28° and the suppression of aerial symptoms at 16° C.

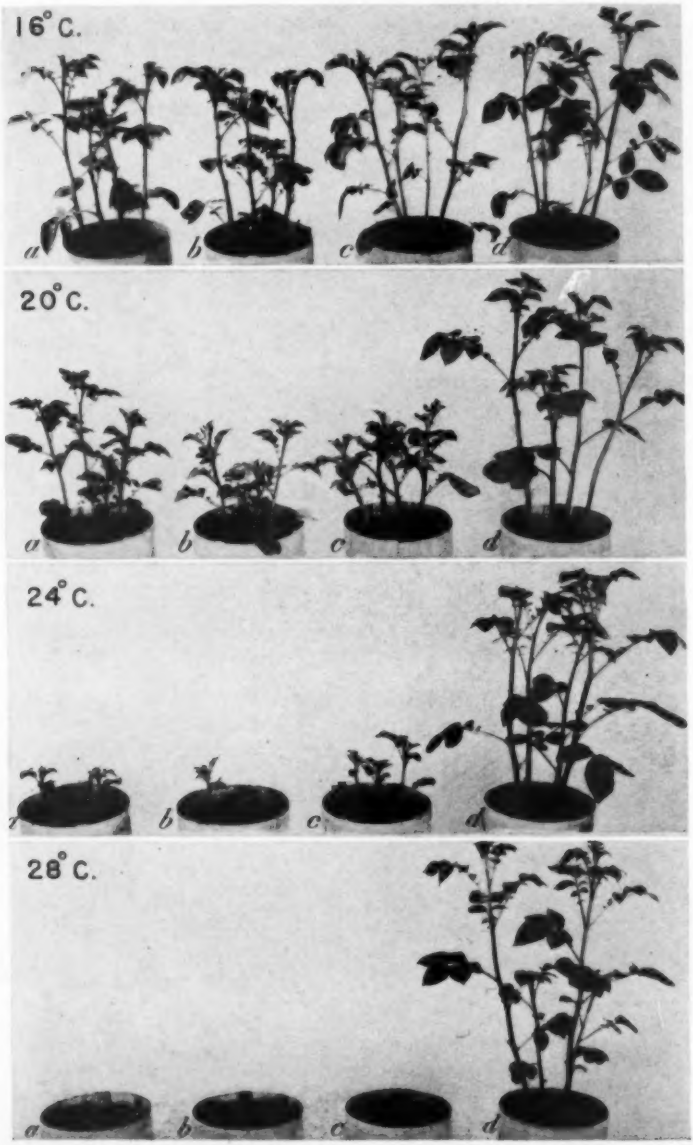

FIGURE 5.—Representative cans from the soil-temperature study with healthy (*d*) and yellow dwarf-infected seed tubers (*a* to *c*) of Russet Rural variety. Compare with figure 4.

development in that year, consisting of general reduction of stands and considerable percentages of early developing secondary symptoms, showed quite clearly that a general spread of the virus had occurred late enough in 1936 to provide infection without visible primary symptoms. A localized very severe epidemic had occurred in Washington County in 1935 in fields planted with local-grown seed tubers of 1934, although diseased plants were rare in that district in the latter year. In 1937 the development of current primary symptoms set in early in central Wisconsin and they continued to develop rapidly after August 1. Any seed tubers used from fields in the path of the 1937 epidemic produced typically poor stands in 1938. Exceptional losses were averted in the latter year by the general introduction of planting stocks from disease-free areas.

Periodic severity of yellow dwarf has been recorded also in Michigan and in New York. Muncie (*6*) pointed out that a field in Michigan contained 0.5 percent, none, and 24 percent of diseased plants in 1929, 1930, and 1931, respectively, although in each year seed tubers from the previous crop on the same field were used. In another case, when seed tubers from a 1930 field showing only 0.1 percent of yellow dwarf were planted in the same field in 1931, 50 percent of the plants were affected. It is significant that in both cases the epidemic development of 1931 followed a low-disease year in 1930. In New York, Taylor (*8*), in describing the development of yellow dwarf on nine varieties and strains of potato, reported a low disease incidence but apparently a serious seasonal spread in 1934, since the number of infected plants in the 1935 crop was as high as 48 percent in one lot. When tubers were saved from healthy-appearing hills of the 1935 crop, in which the disease was so destructive, eight of the lots had no disease in 1936 and the ninth only 2 percent, showing that practically no spread occurred in 1935.

In the course of experimental studies in central Wisconsin from 1933 to 1937, inclusive, tubers from yellow dwarf plants and seed tubers from noninfested areas were planted in adjacent rows in each year except 1936. Seed tubers from the noninfested areas were saved regularly and the disease incidence determined in plantings of the following season. The results of this study in table 7 show that the natural spread was light in 1933, 1934, and 1935 as compared with the extensive dissemination that occurred in 1937.

TABLE 7.—*The natural spread of yellow dwarf in central Wisconsin in 1933, 1934, 1935, and 1937, as shown by tests during each succeeding season of tubers from healthy stock grown alongside yellow dwarf plants*

Year of exposure	Year of test	Hills tested	Nonemerging hills	Hills with yellow dwarf
		Number	*Percent*	*Percent*
1933	1934	300	5	2
1934	1935	200	1	9
1935	1936	300	1	6
1937	1938	700	28	28

The comparative spread of the virus in various localities in the State in a given year was studied in 1934 and again in 1937. In the former year adjacent rows of yellow dwarf tubers of Russet Rural

variety and tubers of a yellow dwarf-free stock of Rural New Yorker were planted near Ashland in the extreme northern part of the State, at Almond in the central area, and at Madison in southern Wisconsin. The relative behavior of the yellow dwarf tubers has already been discussed and the data are presented in table 4. The best stand was in the northern location and thus a greater abundance of inoculum for insect spread was available there than at the other two locations. From each of the exposed healthy hills tubers were saved from which plantings were made in central Wisconsin in 1935 to determine the relative spread at the three locations. The results are given in table 8. They show that spread occurred in all three areas but was least in the northern location.

TABLE 8.—*The relative spread of yellow dwarf in northern, central, and southern Wisconsin in 1934 as shown by planting tests in 1935 of tubers from hills exposed in those areas*

Location in which plants were exposed in 1934	Relative location in Wisconsin	Hills planted in 1935	Hills showing yellow dwarf in 1935 tests
		Number	*Percent*
Ashland	Northern	200	1
Almond	Central	200	9
Madison	Southern	300	7

In 1937 a series of potato plots set up by the departments of horticulture and genetics, University of Wisconsin, in which 19 varieties or strains were grown in 4 randomized replicate blocks in 7 different locations in the State. Four of these were in northern locations—Barron, Oneida, Langlade, and Door Counties. One was at Almond, Portage County, in central Wisconsin. Two were in the southeastern portion of the State—Washington and Walworth Counties. In one of the strains a small percentage of yellow dwarf infection occurred in the seed stock, and thus there were a few secondarily infected plants at each location. In the Almond location the plot adjoined a large field of Russet Rural potatoes in which about 3 percent of the hills showed secondary yellow dwarf infection from the seed pieces. An occasional yellow dwarf plant occurred in Washington and Door Counties in the fields of which the variety plots were each a part. In the remaining locations the only yellow dwarf observed was that introduced in the single strain already noted.

The spread during 1937 was very pronounced at Almond. By September 1 primary symptoms were to be found on most plants in the field. There was a very large population of the clover leafhopper (*Aceratagallia sanguinolenta* (Prov.)) in this section. While the insect was found in the other southern locations it was not abundant and it was absent or rare in the northern counties.

A random sample taken from each composite of the four replicates of each variety at each location was planted in 1938 at Hancock in central Wisconsin. In the case of stocks from Portage and Washinton Counties 40 tubers were saved from each and planted at the rate of 1 tuber per hill. From each of the other locations 20 tubers were used, each tuber being divided between 2 hills. The occurrence of yellow dwarf resulting from tuber infection was recorded and the results are presented in table 9.

TABLE 9.—*The relative spread of yellow dwarf in 19 strains of potato grown in randomized replicate blocks in 7 locations in Wisconsin in 1937*

Variety or strain	Percentage of missing hills (mh) and yellow dwarf (yd) in tests [1] at Hancock in central Wisconsin in 1938 from stocks produced in 1937 in—													
	Barron County		Oneida County		Langlade County		Door County		Portage County		Washington County		Walworth County	
	mh	yd	mh	yd	mh	yd	mh	yd	mh	yd	mh	yd	mh	yd
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Triumph	5	0	3	0	8	0	5	0	53	28	3	0	0	0
Warba	0	0	10	0	3	0	5	0	5	23	0	0	0	0
Irish Cobbler	5	0	0	0	0	0	8	0	18	28	3	0	0	0
Cottrell Cobbler	5	0	0	0	0	0	0	0	25	45	0	0	0	0
100-Day Cobbler	0	0	0	0	0	0	3	0	15	18	0	0	0	0
White-blossomed Cobbler	5	0	5	0	0	0	18	0	68	5	0	0	0	0
Earlaine	0	0	10	0	0	0	----	----	38	23	5	0	0	0
Mesaba	15	0	8	0	0	0	0	0	30	40	0	0	0	0
Houma	8	0	3	0	0	0	0	0	15	38	0	0	3	0
Rural New Yorker	0	0	0	0	0	0	3	0	38	13	0	0	3	0
Pioneer Rural	0	0	3	0	0	0	0	0	20	30	0	0	5	0
Tosnco 4	15	0	15	0	0	0	5	0	48	23	3	0	0	0
Russet Rural	5	0	0	0	0	0	8	0	45	15	0	0	0	0
Russel Rural (Martin strain)	8	0	3	0	0	0	10	0	43	33	0	0	0	0
Chippewa	3	0	3	0	0	0	5	0	8	40	0	0	5	0
Katahdin	----	----	3	0	8	0	13	0	13	40	0	0	5	0
Green Mountain	5	0	0	0	0	0	0	0	23	47	3	0	0	0
Russet Burbank	0	0	0	0	0	0	----	----	5	13	0	0	0	0
Columbia Russet	0	0	0	0	0	0	18	0	13	38	0	0	0	0
Average	4	0	3	0	1	0	6	0	28	28	1	0	1	0

[1] 40-tuber units of the stocks from Portage and Washington Counties; 20-tuber units were planted from he remaining locations.

Several insects have been reported as vectors of the yellow dwarf virus. Koch (*4*) claimed transmission by the peach aphid (*Myzus persicae* (Sulz.)). Muncie (*7*) reported transmission by means of the potato aphid (*Macrosiphum solanifolii* Ashm.) and the potato leafhopper (*Empoasca fabae* (Harris)). Black (*2*), however, was unable to show any one of these insects to be a vector, but he proved definitely that the clover leafhopper did transmit the virus. He considered the last-named insect to be the chief, if not the only, vector. It is not the intent to report in this paper on the insect-transmission studies that the writers have under way, but it is of interest, in view of the confusion which now exists on this point in the literature, to point out the interesting circumstantial evidence that is presented in the studios reported in table 9. Although yellow-dwarf plants were present uniformly in all locations as a result of the random arrangement, general spread of the virus occurred only in the central-Wisconsin plot. Since the potato leafhopper was quite as prevalent in the Walworth County and Washington County plots as in the central-Wisconsin plot, the lack of yellow dwarf spread in these two locations rules out that insect as an important vector of yellow dwarf in this case. In the Walworth County plot there was severe spread of mosaic, indicating the presence of the potato or peach aphid or both in considerable numbers in that location. Since no spread of yellow dwarf occurred, aphids would seem not to have functioned as important vectors of that disease. At the Barron County plot a general spread of spindle tuber occurred without any spread of yellow dwarf and

only a very limited spread of mosaic. This plot was subjected to a heavier grasshopper infestation than any other of the seven and that insect may well have caused the unusual amount of dissemination of the spindle-tuber virus. These facts, together with the heavy infestation of clover leafhoppers at Almond in 1937, seem to leave little doubt that the latter was the principal vector of the yellow dwarf virus in Wisconsin in that year.

The range of yellow dwarf as a destructive disease in Portage County in the epidemics of 1932 and 1937 was restricted to the

FIGURE 6.—Map of the central Wisconsin area showing location (by number) of farms from which tuber samples were secured in the fall of 1937 for studying the natural occurrence of potato yellow dwarf. The area surrounded by the dotted line is that in which the disease was most severe in 1932 and 1937.

eastern half of the county. The outer fringe of this area runs roughly as indicated in figure 6. In the zone immediately to the north and west of this line many growers have used the same seed stock for a long period of years without any tendency for the yellow dwarf virus to be built up in it, although the virus is not entirely absent, for an occasional diseased plant is found. The samples which were collected at random in 1932 from fields in the area to the north, west, and south of the high-disease region were included in the 1933 trials and comprise those under group 2 in table 1. They showed no yellow dwarf. When the epidemic of 1937 got under way another survey of central Wisconsin showed practically the same relation of low-disease and

high-disease zones as in 1932. Many fields which were a total loss in the high-disease zone were from certified seed stock grown only one season in the locality, while in the low-disease zone many growers had used the same seed stock for 10 to 20 years, i. e., throughout the epidemic of 1932 and the years immediately preceding it.

In order to get further data as to the relative spread in these zones during the 1937 epidemic, samples were collected at harvest from fields at random along the highway indicated in figure 6, extending from the low-disease area on the north through the high-disease area and into the area where the disease had been less severe on the south. These samples were planted in 1938 and the stand and yellow dwarf counts were taken. The results are given in table 10. They show that the concentration of the virus was again greatest in the same zones as in 1932. In 1937 the area to the north remained quite free from general spread of the virus as in previous years. There appeared to be an extension of the severe-disease area to the souuth since samples collected on the southern fringe (lot Nos. 17–20) showed relatively high percentages of yellow dwarf and nonemerging hills.

TABLE 10.—*The occurrence of yellow dwarf and missing hills in plantings made from seed tubers collected in the fall of 1937 from fields at random in the low-disease and high-disease areas of Marathon, Portage, and Waushara Counties, Wis., as indicated in figure 6*

Lot No.[1]	Variety	Years of continuous use of seed stock	Nonemerging hills	Yellow dwarf	Lot No.[1]	Variety	Years of continuous use of seed stock	Nonemerging hills	Yellow dwarf
		Number	*Per cent*	*Per cent*			*Number*	*Per cent*	*Per cent*
1	Russet Rural	3	3	0	12	Rural New Yorker	3	43	18
2	do	4	10	0	13	do	3	33	28
3	do	8	3	0	14	do	2	73	18
4	do	6	5	0	15	do	2	48	33
5	do	15	8	0	15a	Chippewa	2	13	60
6	do	4	8	0	15b	Spaulding Rose	2	28	55
7	do	7	5	0	16	Russet Rural	20	18	25
8	Rural New Yorker	7	15	3	17	do	20	13	15
9	do	10	43	0	18	do	2	13	10
10	do	4	18	13	19	do	15	10	10
11	do	7	68	3	20	do	2	43	13

[1] See fig. 6.

A field survey of clover leafhoppers in 1937 showed them to be quite scarce in the low-disease zone to the north and west and very abundant in the high-disease zone. This, no doubt, is a fundamental reason for the existence of clear-cut limits to the severe-disease area. However, there is no such relation here between the occurrence of red clover (*Trifolium pratense* L.) and the occurrence of the leafhopper and the virus as is claimed by Black (*2*) and Mader (*5*) in New York State. In fact, quite the reverse is true, since the high-disease zone in Portage County, being of light acid sandy soil, is a poor clover area and very little of it is grown there. On the other hand, the heavier soil in the low-disease zone just to the north of this county, where the virus and clover leafhoppers are both rare, is a very good red clover area and supports large acreages of it annually. The same may be said of several of the other locations where the plots which were carried in

1937 showed little or no yellow dwarf spread. On the basis of these experiments and observations there is no reason to look upon red clover as the important overwintering host of yellow dwarf in Wisconsin. In the districts where epidemics have been most destructive in this State there must be sufficient carry-over in the insects and in potato tubers or in overwintering hosts other than red clover to provide inoculum in the spring.

DISCUSSION

The object of this investigation has been to throw more light on the development of yellow dwarf under Wisconsin conditions. The disease is distinct from other virus diseases of the potato in that one of the outstanding features is the reduction in emergence of shoots from infected seed tubers. In view of the fact that this vulnerable effect upon the plant is enhanced with increase in soil temperature, it is not surprising that the "poor stand" phase of the disease has been the outstanding one in central Wisconsin. For various reasons which need not be discussed here the majority of the crop is planted relatively late, i. e., during the first half of June. This and the fact that the sandy soil which prevails in that section has a rather high specific heat combine to bring about in many seasons the optimum conditions for severe disease manifestations.

In view of the fact that plants which are infected from the seed piece usually produce tubers that are reduced in size and few in number, the virus might well be largely self-eliminating were it not for its dissemination during the growing season. The environmental studies show that high temperatures of air and soil both tend to enhance the expression of top symptoms while cool air and even cool soil tend to suppress them. Thus it becomes evident that such spread may be general without causing current-season symptoms on tops or tubers depending on the prevailing climate. In a cool season the evidence of current-season spread may be completely masked even though it occurred fairly early in the season. The uncertainty of maintaining yellow dwarf-free seed stocks in some areas is therefore greatly increased.

The report of Black (*2*) that the clover leafhopper is a vector of the virus has been confirmed. Studies of the epidemic of 1937 in central Wisconsin show a close correlation of seasonal spread of the virus with the abundance of that insect. A comparison of comparable seed lots grown in various parts of the State shows that there is no correlation of yellow dwarf spread with the occurrence of the potato leafhopper, nor with the dissemination of aphid-transmitted viruses such as those of the mosaics and spindle tuber.

It should also be made clear that the section in which yellow dwarf has been most serious in Wisconsin supports a negligible acreage of red clover. This crop does not appear to be an important source of overwintering inoculum. On the contrary, an area only a few miles removed from that in which yellow dwarf occurs to some extent annually and in severe epidemic form periodically has remained free from more than a negligible occurrence of the disease for the past 7 years or longer in spite of the fact that it supports a substantial acreage of that legume. The main source of overwintering inoculum in the yellow dwarf section of central Wisconsin may well be the seed tuber, while the extent of seasonal spread and subsequent development of

secondary symptoms in epidemic form may depend largely upon the relative occurrence of clover leafhoppers.

In the 1937 epidemic in Portage County, 19 varieties or strains of potato were exposed to natural infection. While the 1938 tests (table 9) show that each of these clones produced some infected tubers in 1937, it should be pointed out that Russet Burbank was distinctly the lowest of the group when percentages of both missing hills and yellow dwarf are considered. This is in accord with the observation of Taylor (*8*) who found this variety to be the least infected in a group exposed to natural infection in New York State. Inasmuch as certain individuals of the clone became infected it would seem plausible that the noninfected ones were escapes. The possibility of escape because of a preferred position as to exposure in 1937 is very remote, since the sample of seed tubers was taken from a mixture of the yield of a replicate from each of four blocks in which the arrangement of varieties was randomized. Even though this may prove to be a case of escape, dependent presumably upon the avoidance of the variety by the insect vector, its occurrence in both New York and Wisconsin is sufficiently significant to warrant further study.

SUMMARY

The symptoms of yellow dwarf under Wisconsin conditions are discussed. One important phase of the symptomatology not previously reported is the nonemergence of plants from infected seed tubers.

The study of temperature relations shows that the top symptoms develop most rapidly and severely at high air temperatures and they may be entirely suppressed at 16° C. Low soil temperatures favor germination and emergence from infected seed tubers and tend to suppress the appearance of top symptoms. High soil temperatures tend to prevent emergence and to hasten the appearance of top symptoms. The "poor-stand" phase of yellow dwarf in the field is associated with high soil temperatures in the period.

The sporadic appearance of yellow dwarf in epidemic form is discussed. It is shown that the greatest amount of dissemination in 1937 was in the eastern part of Portage County in central Wisconsin where the clover leaf hopper was most prevalent. No field evidence of spread by the potato leafhopper or aphids was secured.

A study of contiguous low-disease and high-disease areas in central Wisconsin during the priod from 1932 to 1938 shows no correlation between red clover plantings and yellow dwarf epidemics. It appears that other sources of inoculum are more important in central Wisconsin.

It is pointed out that Russet Burbank tended to escape infection in the section in central Wisconsin where 18 other varieties or strains of potato became heavily infected in the epidemic of 1937.

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EFFECT OF RELATIVE HUMIDITY ON VIABILITY, MOISTURE CONTENT, AND RESPIRATION OF WHEAT, OATS, AND BARLEY SEED IN STORAGE[1]

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INTRODUCTION

It is well known that seeds deteriorate more rapidly in humid than in arid climates. Under dry conditions some agricultural seeds may be stored for 10 years or more without sufficient loss in viability to make their use unprofitable. In a previous study, Robertson and Lute [2] found that wheat, oats, and barley stored in a dry room for 15 years retained over 80 percent of their original ability to germinate. In a humid atmosphere, these seeds may lose as much in a few months.

In humid regions the detrimental effect of moisture presents a problem of economic importance when seeds are stored for long periods. The first step in solving this problem is, obviously, a study of the tolerance of seeds to atmospheric moisture. If it were known how much moisture the seeds would tolerate for a given length of time at a given temperature, this information could be used as a guide in selecting storage conditions.

In an attempt to solve this problem an experiment was set up in 1932 in which the effect of atmospheric humidity on rate of loss in viability, respiration rate, and moisture content of wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), and barley (*Hordeum vulgare* L.) was studied.

Respiration rate was studied primarily to see how closely respiration was related to loss in viability. Moisture content was determined because this variable is a function of the humidity and may be used as an index of humidity where no direct measurements are available.

MATERIALS AND METHODS

Humidity control was obtained by the use of glass desiccators containing sulfuric acid solutions. The moisture content of the grain in storage was determined by weighing each sample used for germination as it went into and came out of the desiccators. Percent moisture was calculated on the oven-dry basis. The moisture percentage was considered as the total difference. This, undoubtedly, caused a slight error since loss of solids through the process of respiration was considered as moisture. This error is noticeable in table 6, which shows the moisture content of the grain when the various germination samples were taken. However, the discrepancy is slight when compared with the total amount of moisture contained in the grain at the end of the test period. Respiration rate was estimated on the basis of carbon dioxide found in samples of the air in the desiccators.

[1] Received for publication January 17, 1939.

[2] ROBERTSON, D. W., and LUTE, A. M. GERMINATION OF SEED OF FARM CROPS IN COLORADO AFTER STORAGE FOR VARIOUS PERIODS OF YEARS. Jour. Amer. Soc. Agron. 29: 822-834. 1937.

Marquis wheat, Colsess barley, and Colorado 37 oats grown in 1922, 1926, and 1931 were used in the experiment. The samples were taken from the same lots studied by Robertson and Lute.[2]

Fifteen crystallizing dishes, each containing a sample of 200 seeds, were placed in each desiccator over sulfuric acid solutions. Each desiccator had a capacity of 8,400 cc., and the crystallizing dishes were 50 mm. in diameter by 35 mm. deep. The acid varied in concentration in the different desiccators to produce the range in humidity. The data of Wilson [3] were used in calculating the concentrations of acid required.

The experiment was run in a thermostatically controlled room at approximately 70° F., except that the thermostat was disconnected while the last set of samples was still under study and these were subjected to a wide range of temperature for the last year, the temperature often reaching 100°.

At suitable intervals, samples of from 500 to 1,000 cc. of air were drawn from the desiccators and analyzed for CO_2. At the same time grain samples were removed for moisture and germination determinations.

The absorption apparatus described by Gardner [4] was used for the CO_2 analyses. The samples of gas were drawn through 25 cc. of 0.1 normal NaOH in the absorbing flask which contained also a few drops of normal butyl alcohol and phenolphthalein. After the samples were drawn, the flask was disconnected and 10 cc. of 10-percent $BaCl_2$ added. The contents were then titrated with 0.1 normal HCl in the closed flask through a hole in the stopper.

After each sampling, the lids of the desiccators were removed and the air changed by fanning. The CO_2 in the outside air was determined at each change of air and a correction made for this at the time of the next sampling. A blank determination was used to correct for the CO_2 initially in the absorption flask.

The experiment was run, first with seed treated with Ceresan, but later the possibilities of using copper carbonate, mercuric chloride, and formaldehyde were studied, and finally untreated seed was used.

EXPERIMENTAL RESULTS

The use of an excess of Ceresan where a gram or more of this material was shaken with the seed and the excess not removed was found to be injurious at high humidities. This effect is shown in tables 1 and 2. In table 1 the first and third sets of seed were treated with an excess of Ceresan. Percent germination dropped very low within a week in nearly every case. The second set treated with an excess of copper carbonate deteriorated more slowly. Table 2 shows that seed in a saturated atmosphere, covered with Ceresan, was killed within 7 days, while seed untreated or lightly dusted with Ceresan survived much longer.

Table 3 shows the moisture absorbed, the rate of CO_2 production, and the percent germination of 1931 wheat in a saturated atmosphere for a period of 28.5 days measured at 1- to 2-day intervals. In this test, grain was treated with an excess of Ceresan and then shaken

[3] WILSON, ROBERT E. HUMIDITY CONTROL BY MEANS OF SULFURIC ACID SOLUTIONS, WITH CRITICAL COMPILATION OF VAPOR PRESSURE DATA. Jour. Indus. and Engin. Chem. 13: 326–331, illus. 1921.

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over a sieve to remove the excess. The data show that viability decreased more slowly than when the excess Ceresan was not removed, but quite irregularly, indicating that some lots were injured by the treatment.

TABLE 1.—*Viability and moisture content of wheat, oats, and barley when treated with an excess of Ceresan and copper carbonate, and stored in air at 100 percent relative humidity for periods up to 85 days in preliminary tests made at Fort Collins, Colo.*

Grain and time in desiccator (days)	Germination of—			Moisture content of—		
	Lot 1 [1]	Lot 2 [2]	Lot 3 [1]	Lot 1 [1]	Lot 2 [2]	Lot 3 [1]
Wheat:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	95.5	95.5	95.5	5.09	5.72	5.72
7		97.0	46.0		17.62	21.78
14		50.0	21.0		20.87	24.35
21		49.0	0		23.52	27.92
28		29.0	0		23.71	30.20
35		6.0	4.0		26.80	29.72
42		0	5.0		32.60	29.96
49		0	44.0		32.55	
70	16.0					
85				38.95		
Oats:						
0	97.0	98.5	98.5		6.16	6.16
7		99.0	86.0		19.43	21.65
14		59.5	2.0		22.49	24.28
21		51.0	0		24.65	26.70
28		39.0	0		26.62	29.68
35		5.0	0		29.63	30.64
42		0	0		31.79	27.68
49		0	0		33.84	
70	0					
85	0					
Barley:						
0		96.5	96.5		5.43	5.43
7		98.0	6.0		19.43	20.08
14		89.5	69.0		22.80	23.38
21		68.5	2.0		24.63	26.31
28		68.0	14.0		26.33	29.31
35		35.0	0		28.87	31.45
42		0	1.0		19.95	29.33
49		0	1.0		30.56	
70	21.5					
85	16.0			24.02		

[1] Treated with an excess of Ceresan; excess not removed.
[2] Treated with an excess of copper carbonate.

TABLE 2.—*The effect of Ceresan treatment (excess not removed) on the viability of Marquis wheat stored for periods up to 28 days at 100 percent relative humidity*

Time (days)	Germination			Time (days)	Germination		
	No treatment	Dusted	Covered		No treatment	Dusted	Covered
	Percent	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*
7	93.5	90.0	0	21	46.5	65.0	
14	88.5	54.0	0	28	38.5	36.0	

Table 4 shows the viability of wheat, oats, and barley for 527 days at humidities ranging from 70.2 to 6.7-percent saturation. In the extremely dry atmospheres very little injury was noted during the period, though all seed received the excess Ceresan treatment. At 42.3-percent saturation (table 4), the percent germination for wheat was slightly lower at the end of 527 days than the untreated grain after 1,032 days (table 5), indicating some damage at this humidity.

TABLE 3.—*Effect of Ceresan treatment on the moisture absorption, the CO_2 production, and the viability of Marquis wheat (1931 crop) when stored at 100 percent relative humidity and 86° F. for periods up to 28.5 days*

[Grain treated with an excess of Ceresan then shaken over a sieve to remove the excess]

Time in desiccator (days)	Moisture absorbed	CO_2 produced per 1,000 gm. of grain per day	Germination	Time in desiccator (days)	Moisture absorbed	CO_2 produced per 1,000 gm. of grain per day	Germination
	Percent	*Milligrams*	*Percent*		*Percent*	*Milligrams*	*Percent*
0.0	9.1	------	98.5	13.5	35.6	121.5	65.0
1.5	17.0	1.9	95.0	14.5	36.3	138.3	70.0
2.5	21.9	5.1	94.5	15.5	37.3	151.6	81.0
3.5	23.2	17.2	91.0	16.5	36.6	97.5	85.0
4.5	27.6	12.7	81.0	17.5	37.1	150.8	72.0
5.5	28.4	29.5	84.5	18.5	37.4	99.6	80.5
6.5	29.3	30.1	75.0	19.5	39.7	210.9	------
7.5	32.3	58.5	84.5	20.5	39.7	172.9	70.5
8.5	32.3	57.7	91.5	22.5	41.3	119.6	80.0
9.5	34.4	64.7	80.0	24.5	37.7	149.5	66.5
10.5	35.1	85.1	82.5	26.5	37.7	130.2	59.5
11.5	35.7	96.1	87.5	27.5	39.4	106.7	38.0
12.5	36.6	116.5	86.5	28.5	39.7	81.1	89.0

The reduction in germination was slightly less for oats and barley than for wheat. Particularly this is true for the grain stored at 42.3-percent humidity. A possible explanation of this difference may be found in the protection afforded the germ by the hulls of oats and barley.

TABLE 4.—*Viability of wheat, oats, and barley produced in 1922, 1926, and 1931, when treated with an excess of Ceresan and stored in air at different relative humidities for periods up to 527 days*

Grain and time in desiccator (days)	Germination at—											
	70.2 percent humidity			42.3 percent humidity			19.1 percent humidity			6.7 percent humidity		
	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Wheat:												
0	93.5	92.0	95.5	93.5	92.0	95.5	93.5	92.0	95.5	93.5	92.0	95.5
71	36.0	50.3	63.5	74.5	83.0	85.0	90.5	90.0	90.5	93.5	89.0	84.5
114	28.0	------	------	70.0	------	------	81.5	------	------	88.5	------	------
142	21.5	------	------	73.0	------	------	85.0	------	------	93.5	------	------
170	------	31.0	57.0	------	67.5	63.0	------	81.5	86.0	------	86.5	83.5
302	.0	1.0	27.0	52.0	56.0	51.0	82.0	75.0	67.0	86.5	85.5	85.0
527	.0	.0	.0	47.0	52.5	48.0	80.0	81.0	67.5	80.0	77.5	73.0
Oats:												
0	92.5	97.0	97.0	92.5	97.0	97.0	92.5	97.0	97.0	92.5	97.0	97.0
71	25.5	64.0	23.5	75.0	92.5	86.5	87.5	98.5	89.0	87.0	95.5	100.0
114	------	51.5	------	83.0	------	------	86.5	------	------	91.0	------	------
142	------	57.0	------	86.5	------	------	77.5	------	------	86.0	------	------
170	10.0	------	.5	------	89.0	85.5	------	89.5	87.5	------	95.0	87.6
302	.0	1.0	.0	69.0	89.5	76.0	81.5	92.0	87.0	83.0	88.0	84.0
527	.0	.0	.0	78.0	84.0	73.0	72.0	91.0	82.0	82.0	95.0	84.0
Barley:												
0	90.0	95.5	96.5	90.0	95.5	96.5	90.0	95.5	96.5	90.0	95.5	96.5
71	84.5	93.5	92.5	90.8	91.5	90.5	90.0	86.5	94.0	94.0	94.0	97.0
114	74.0	------	------	86.5	------	------	91.5	90.0	------	89.5	------	------
142	69.5	------	------	89.5	------	------	89.5	------	------	92.0	------	------
170	------	75.0	85.0	------	90.0	86.5	------	------	88.0	------	87.5	94.5
302	1.0	31.0	60.0	87.0	86.0	84.0	90.0	91.0	83.0	93.0	93.0	94.0
527	.0	.0	.0	79.5	82.5	87.5	87.0	82.0	82.0	90.0	88.0	91.5

Trials were next made with seed treated with $HgCl_2$ by the method of Norton and Chen [5] and with a formaldehyde solution (1 pint of 40-percent formaldehyde diluted with 40 gallons of water). The $HgCl_2$ treatment killed all the seed within 4 days and the formaldehyde treatment was ineffective in preventing mold.

The experiment was then continued with untreated seed over a humidity range of from 98-percent saturation to 57.6-percent saturation. The results are shown in tables 5, 6, and 7, and graphically in figure 1. These results should be comparable to conditions of normal

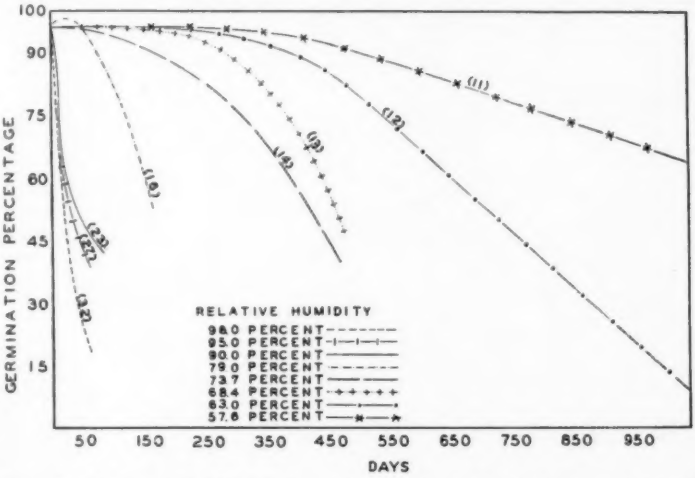

FIGURE 1.—Average viability and moisture content of wheat, oats, and barley grown in 1931 and stored in desiccators at different relative humidities for 1,032 days or less. Each curve represents a different relative humidity. Moisture content of the grain at the end of the storage period is given in parentheses.

storage since stored grain is not ordinarily treated with fungicides. It is possible that fungi as well as normal deterioration accompanying respiration were responsible for part of the loss in viability at the higher humidity. Mold developed on all of the grain at 79-percent saturation or higher. It will be noted from table 5 that the rate of loss in viability is very much accelerated as the humidity increases from 57.6-percent saturation to nearly saturation. Pronounced injury is noted in less than a month at 90 percent or higher. Three samples still germinated quite well at the end of 1,032 days at the lower humidity, though most of the germination dropped to a low figure before that time. The older grain showed the most rapid decline in germination at all humidities.

[5] NORTON, J. B. S., and CHEN, C. C. SOME METHODS FOR INVESTIGATING INTERNAL SEED INFECTION. Phytopathology 10:399–400. 1920.

TABLE 5.—*Viability of untreated wheat, oats, and barley produced in 1921, 1926, and 1931, when stored in desiccators in atmospheres of different relative humidities for periods up to 1,032 days*

Grain and time in desiccator (days)	Germination at—																							
	98.0-percent humidity			95.0-percent humidity			90.0 percent humidity			79.0-percent humidity			73.7-percent humidity			68.4-percent humidity			63.0-percent humidity			57.6-percent humidity		
	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed
Wheat:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
0	89.5	86.5	98.0	89.5	86.5	98.0	89.5	85.5	94.0	95.0	95.0	97.5	95.0	95.0	97.5	95.0	95.0	97.5	95.0	95.0	97.5	95.0	95.0	97.5
14	30.0	38.0	65.5	34.0	41.0	60.5	53.5	64.0	89.0	78.0	96.0	99.0												
21	23.5	27.5	43.5	28.0	31.0	49.5	23.0	32.0	58.5															
30	19.0	24.0	39.0	22.0	33.0	45.0	14.0	23.0	50.0															
35										84.0	73.0	97.0												
38	13.0	18.0	33.0	14.0	17.0	47.0	16.5	25.0	51.0															
56	.0	.0	19.0	7.5	21.5	29.5	17.0	17.5	42.0															
100										24.0	56.0	83.0												
158										2.0	32.0	61.0												
219													48.0	89.0	90.0									
300													44.0	72.0	81.0	71.0	89.0	96.0						
454													6.5	50.0	87.0	52.0	85.0	92.0	77.0	94.0	97.0			
1,032													.0	2.0	55.0	.0	7.0	48.0	48.0	70.0	95.0	83.5	90.0	95.0
(1)										.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	4.0	2.0	25.0	76.0
Oats:																						80.0	92.0	89.0
0	87.5	96.0	97.0	87.5	96.0	97.0	87.5	96.0	97.0	91.0	97.0	98.0	91.0	97.0	98.0	91.0	97.0	98.0	91.0	97.0	98.0	91.0	97.0	98.
14	52.5	60.0	66.0	55.0	63.0	63.5	64.0	69.0	76.0	89.0	94.0	98.0												
21	41.0	52.0	44.5	45.0	56.0	51.0	41.5	53.0	55.0															
30	35.0	42.0	47.0	30.0	50.0	50.0	32.0	58.0	46.0															
35										74.0	91.0	98.0												
38	22.0	35.0	47.0	30.0	39.0	41.0	35.0	52.0	48.0															
56	.0	.0	1.0	16.5	29.0	36.5	1.0	41.0	39.5															
100										43.0	67.0	75.0												
158										9.0	24.0	70.0												
219													64.0	78.0	81.0									
297													45.0	65.0	78.0	72.0	78.0	87.0						
454													33.0	40.0	66.0	64.0	72.0	85.0	76.0	89.0	89.0			
1,032													.5	.0	7.0	14.0	13.0	33.0	55.0	69.0	68.0	74.0	89.0	86.0
(1)										.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2.0	20.0	17.0	32.0
																						73.0	80.0	86.0

Barley:																								
0	88.0	95.0	97.0	88.0	95.0	97.0	88.0	95.0	97.0	95.0	93.0	96.5	95.0	93.0	96.5	95.0	93.0	96.5	95.0	93.0	96.5	95.0	93.0	96.5
14	69.5	73.5	73.5	73.0	75.0	77.0	80.0	82.0	83.5	95.0	96.0	98.0												
21	62.5	70.0	58.5	68.0	68.0	65.0	65.5	73.0	67.5															
30	55.0	68.0	64.0	59.0	65.0	65.0	63.0	70.0	70.0															
35										86.0	94.0	99.0												
38	53.0	68.0	49.0	52.0	48.0	66.0	47.0	67.0	60.0															
56	9.0	19.5	42.0	27.0	63.5	57.0	35.0	67.5	60.5															
100										53.0	78.0	88.0												
158										19.0	57.0	26.0	69.0	87.0	94.0									
219													56.0	87.0	93.0	78.0	90.0	97.0						
300													35.0	77.0	89.0	57.0	89.0	92.0	90.0	95.0	96.0			
454													1.0	12.0	69.0	16.0	54.0	82.0	62.0	87.5	92.0	86.0	91.0	96.5
1,032											1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	22.0	26.0	67.0	85.0
(1)																						64.0	82.0	

[1] Seeds stored in sacks at room temperature, December 1937.

TABLE 6.—*Moisture content of untreated wheat, oats, and barley grown in 1922, 1926, and 1931, when stored in desiccators in atmospheres of different relative humidities for periods up to 1,032 days*

Grain and time in desiccator (days)	Moisture content of seed at—																							
	98.0-percent humidity			95.0-percent humidity			90.0-percent humidity			79.0-percent humidity			73.7-percent humidity			68.4-percent humidity			63.0-percent humidity			57.6-percent humidity		
	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed
Wheat:	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
0	8.03	7.83	8.07	8.03	7.83	8.07	8.03	7.83	8.07	7.44	7.27	7.47	7.44	7.27	7.47	7.44	7.27	7.47	7.44	7.27	7.47	7.24	7.27	7.47
14	21.27	24.73	25.91	23.82	23.79	24.62	21.30	20.86	21.63	16.26	15.86	15.95												
21	27.20	28.15	29.31	25.33	25.52	26.36	22.17	21.82	22.86															
30	31.06	30.16	32.60	26.16	26.22	27.59	24.31	22.27	22.98															
35										16.51	17.05	15.79												
38	30.08	33.93	33.05	27.99	28.66	28.59	26.43	23.09	23.43															
56	27.07	28.81	34.22	23.35	24.03	27.04	20.72	20.94	23.18															
100										15.74	15.39	15.69												
158										15.82	15.15	15.52	14.40	13.85	14.24									
219													14.27	14.14	13.89	13.21	13.23	12.89						
297													14.08	14.08	13.37	13.76	13.40	13.32	12.31	12.23	11.77			
408													13.85	13.69	13.65	12.86	13.06	12.69	12.92	11.65	11.06	10.92	10.81	10.42
1,032										14.12	14.42	12.29	13.54		12.58	12.65	12.43	12.06	11.71	11.65	11.10	11.00	10.54	10.39

BLE 6.—*Moisture content of untreated wheat, oats, and barley grown in 1922, 1926, and 1931, when stored in desiccators in atmospheres of different relative humidities for periods up to 1,032 days*—Continued

Grain and time in desiccator (days)	Moisture content of seed at—																									
	98.0-percent humidity			95.0-percent humidity			90.0-percent humidity			79.0-percent humidity			73.7-percent humidity			68.4-percent humidity			63.0-percent humidity			57.6-percent humidity		
	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed	1922 seed	1926 seed	1931 seed
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Oats:																								
0	7.49	7.74	8.14	7.49	7.74	8.14	7.49	7.74	8.14	7.49	7.74	8.14	7.49	7.74	8.14	7.49	7.74	8.14	7.49	7.74	8.14	7.49	7.74	8.14
14	24.57	26.22	25.96	22.94	23.64	23.87	20.01	20.53	20.79	15.56	16.25	17.09												
21	26.90	28.43	28.57	23.95	24.64	24.90	21.28	21.28	21.52															
30	28.19	30.82	31.15	24.76	27.53	27.40	21.26	22.99	22.17															
35										15.37	16.06	16.93												
38	28.67	31.41	30.70	24.77	25.12	26.94	21.07	21.38	22.89															
56	24.45	26.62	27.97	22.27	24.14	23.86	28.85	20.40	20.77															
100										15.27	16.12	16.95												
158										15.95	15.94	16.73	14.03	14.66	15.27									
219													13.89	14.57	15.35	12.87	13.32	14.20						
297													13.32	13.29	16.95	12.21	13.67	14.67	12.14	12.43	13.47			
408													13.35	14.08	14.77	12.71	13.05	13.46	11.65	11.62	11.24	10.92	10.81	10.42
1,032										12.10	14.21	14.67	12.93	13.46	14.68	12.14	12.86	13.34	11.71	11.96	12.46	10.67	10.67	11.27
Barley:																								
0	7.45	7.90	7.90	7.45	7.90	7.90	7.45	7.90	7.90	7.45	7.90	7.90	7.45	7.90	7.90	7.45	7.90	7.90	7.45	7.90	7.90	7.45	7.90	7.90
14	24.82	26.25	25.48	22.80	23.60	23.70	19.18	21.61	21.15	15.73	17.24	15.54												
21	28.91	30.82		24.45	25.28	25.08	21.63	23.00	22.48															
30	32.76	32.96	32.53	27.99	27.28	26.94	24.65	27.10	23.63															
35										15.92	17.00	16.42												
38	31.70	34.27	32.70	28.06	26.82	28.08	23.65	23.77	23.49															
56	27.10	24.86	28.36	26.99	32.87	26.43	28.65	22.97	22.53															
100										15.79	17.04	17.19												
158										15.74	17.00	16.21	14.34	15.60	14.69									
219													14.16	15.55	14.65	12.96	14.18	13.45						
297													13.46	16.98	14.11	13.13	14.30	10.98	12.04	13.51	12.54			
408													13.41	15.87	12.56	12.53	14.05	11.19	11.49	12.32	11.66	10.15	11.37	10.49
1,032											16.40	14.41	12.90	15.31	13.54	12.56	14.55	11.43	11.60	13.35	11.99	10.44	12.32	10.67

TABLE 7.—*CO_2 produced per 1,000 gm. per day of untreated wheat, oats, and barley when stored in desiccators in atmospheres of different relative humidity for periods up to 1,032 days*

Grain and time in desiccator (days)	CO_2 produced per 1,000 gm. of grain per day at—							
	98 percent humidity	95 percent humidity	90 percent humidity	79 percent humidity	73.7 percent humidity	64.8 percent humidity	63.0 percent humidity	57.6 percent humidity
	Milligrams	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*	*Milligrams*
Wheat:								
0–14	36.0	35.7	9.4	2.1				
14–20	113.4	112.1	88.5					
20–30	146.8	78.2	58.1					
14–35				5.2				
30–38	345.7	81.7	34.4					
38–56	293.6	142.7	30.2					
35–100				28.7				
100–158				37.6				
0–158					1.5			
158–219					3.8			
0–181						0.0		
219–300					6.2	0		
0–300							0.0	
300–454					9.6	2.0	0	
0–454								0.1
454–1,032					1.5	2.7	.7	.1
Barley:								
0–14	35.2	27.6	9.4	2.0				
14–20	103.2	90.0	88.5					
20–30	94.3	54.5	58.1					
14–35				3.4				
30–38	178.1	62.3	24.4					
38–56	255.3	57.0	30.2					
35–100				28.4				
100–158				8.5				
0–158					2.0			
158–219					7.8			
0–181						.3		
219–300					3.9	0		
0–300							.1	
300–454					6.6	1.4	.3	
0–454								.4
454–1,032						.1	.5	.3
Oats:								
0–14	46.9	41.0	18.9	2.3				
14–20	148.3	126.9	107.4					
20–30	137.2	86.9	55.1					
14–35				4.1				
30–38	211.6	85.1	44.7					
38–56	279.8	119.3	38.0					
35–100				36.3				
100–158				27.8				
0–158					3.9			
158–219					8.4			
0–181						.4		
219–300					9.5	0		
0–300							.3	
300–454					6.3	4.1	0	
0–454								.4
454–1,032					2.1	5.2	.1	.2

The data in table 6 show the moisture content of grain at each humidity. It will be seen that the initial moisture in the grain before the experiment started was a little more than 2 percent lower than that found at 57.6-percent saturation at the end of 1,032 days of storage. Figure 1, in which the average moisture of the grains grown in 1931 is given on the different humidity curves, shows a decrease from 32 percent to 11 percent as the humidity decreased from 98.0- to 57.6-percent saturation. Table 5 shows that severe injury resulted in less than 1,032 days at 57.6 percent, in less than 454 days at 68.4 percent, in less than 100 days at 79 percent, and in less than 30 days above 90 percent. In figure 1, in which the average germination of wheat, oats, and barley grown in 1931 is plotted against

time, the general trend of germination is clearly shown at the different relative humidities.

The tests indicate that equilibrium is reached in about 30 days for grain stored in atmospheres of over 79.0-percent relative humidity. For humidities lower than this, the exact time required for equilibrium to be reached was not determined. However, the indications are that all of the grains had reached equilibrium by the time the first moisture sample was taken. The data show that stored grain tends to reach equilibrium with the surrounding air in a rather short period. The moisture equilibrium of the different grains varied slightly in atmospheres of the same relative humidity.

Table 7 shows the respiration rate as measured by CO_2 production and indicates a close relationship between respiration, moisture content of grain, and atmospheric moisture. Whether loss in viability is a direct result of respiration or merely incidental to respiration is not deducible from the experiment.

DISCUSSION

While the results of the experiment show that the decrease in viability due to moisture in the atmosphere depends on the age and condition of the grain when it goes into storage as well as on the relative humidity, they also show that grain in even the best condition will not survive long when the atmospheric moisture approaches saturation at the temperature studied. For example, very serious damage occurred in less than a month to all grain stored at 90-percent relative humidity or higher, while some of the grain lasted nearly 3 years with small damage at 57.6 percent (fig. 1). Similar results are reported for oats by Bakke and Noecker.[6] They found that grain containing 15 percent of moisture and less showed a germination of 91 percent and above at the end of the experiment. Grain containing a greater percentage of moisture ranged from 3 to 85 percent in germination at the end of the experiment. Their experiments were of short duration.

The data in the germination table should be useful as a guide in predicting the approximate maximum time seed can be kept in storage at the temperature studied without serious injury. Since the percentage of moisture in the grain may be used as an estimate of the approximate humidity of the storage environment, it may also be used directly in estimating the probable maximum life of the grain. It will be noted from the moisture tables and figure 1 that approximate equilibrium is reached within 2 weeks when grain is stored in atmospheres above 79-percent relative humidity. On the basis of these figures, grain containing more than 20 percent of moisture cannot be expected to last more than a month without serious injury if the moisture content does not decrease; while grain with 10 percent of moisture might last as long as 3 years if in good condition at the beginning. Either the relative humidity or the percentage of moisture in the grain can be used as a valuable criterion in predicting the probable rate of deterioration of wheat, oats, and barley in storage.

[6] BAKKE, A. L., and NOECKER, N. L. THE RELATION OF MOISTURE TO RESPIRATION AND HEATING IN STORED OATS. Iowa Agr. Expt. Sta. Research Bull. 165, pp. [319]-336, illus. 1933.

SUMMARY

A study of the effect of relative humidity on the rate of loss in viability of wheat, oats, and barley in storage gave the following results:

(1) Heavy treatments with Ceresan before storage decreased the length of life of seeds stored at high humidities.

(2) The length of life of both treated and untreated seeds in storage increased as the humidity decreased over the range studied. Serious injury was suffered by all grains at 100-percent saturation within a month. The injury decreased with decreased humidity. Only a slight loss in viability was found in some samples at the end of 1,032 days' storage in an atmosphere of 57.6-percent saturation.

(3) Respiration, as measured by CO_2 production, increased regularly with relative humidity.

(4) Moisture percentage changed more consistently with humidity than either viability or respiration.

(5) The data showing the rates of change of moisture and viability with humidity offer a means of predicting the maximum time which would be safe for storage under any given relative humidity, assuming temperature conditions comparable to those of the experiment.

(6) Heavy fungus growth developed on all grain at the higher humidity when the grain was not treated with a fungicide. The data do not show what influence these organisms and the bacteria that probably accompanied them had on the decrease in viability of the seed.

SIGNIFICANCE OF VARIATION IN HAM CONFORMATION[1]

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INTRODUCTION

The conformation of the hams is one of the major characteristics considered in the selection of hogs for slaughter. A relatively short, plump, well-muscled ham having a moderately thick covering of external fat and a high proportion of edible meat is the type in greatest demand by consumers. The objects of the study here reported were to determine the relationships of certain anatomical factors to this desired conformation and to obtain additional facts regarding their scientific and practical significance.

Previous work [2] showed that as the type of hog ranges from large to small there is an improvement in the conformation or increase in plumpness of the hams. In a later study [3] it was found that with these changes there were increases in the percentages of separable fat and total edible portion and decreases in separable lean and skin and bone of the ham. The most striking change was in the proportion of fat.

EXPERIMENTAL PROCEDURE

The hams used in this study were from Poland China hogs produced at the Agricultural Research Center, Beltsville, Md. Of the total of 59 hams, 9 were from large-type hogs, 38 from intermediate, and 12 from small-type hogs. Beginning at 72 days of age, all animals received, in self-feeders, No. 2 yellow shelled corn and a mixture of tankage 50 parts, linseed meal 25 parts, and alfalfa leaf meal 25 parts, with an adequate mineral mixture. As they individually reached the weights of approximately 225 pounds the hogs were slaughtered. The actual range in final feed-lot weight was from 212 to 242 pounds.

Immediately prior to slaughter the animals were judged individually for type by a committee of three qualified judges employed in the United States Department of Agriculture. After the carcasses had been chilled for 72 hours, the index of ham plumpness was determined, based on measurements taken as follows: (1) Obtaining the length from the lowest point of the aitchbone to the center of the inside of the hock joint located at the bony projection that may be felt under the skin; (2) determining the circumference at the midpoint of the first measurement by locating three or four points on the ham equidistant from the plane through the center of the hock joint, such points being marked with sharp metal skewers and the ham being encircled with a steel tape immediately below the skewers for measurement; and (3) multiplying the second measurement by 100 and dividing by the first measurement, thereby obtaining the index of plumpness. Other car-

[1] Received for publication March 3, 1939.

[2] HANKINS, O. G. RELATION BETWEEN TYPE IN HOGS AND THE PLUMPNESS OF THEIR HAMS. Amer. Soc. Anim. Prod. Proc. 27: 120–123. 1934.

[3] ——— and ELLIS, N. R. A STUDY OF HAM COMPOSITION WITH SPECIAL REFERENCE TO TYPE OF HOG. Amer. Soc. Anim. Prod. Proc. 28: 111–116. 1935.

cass measurements considered in the study were length of hind leg from the lowest point of the aitchbone to the coronary band of the foot, average thickness of back fat and ham fat, and width of carcass through the hams at the top point of the aitchbone. These measurements and those from which the index of plumpness was derived were taken according to the method reported by Hankins and Ellis.[4]

In removing the hams from the carcass, the cut was made just behind the second sacral vertebra and at right angles to the hind leg. The leg was then cut off through the hock joint. After each ham was trimmed smoothly, the thicknesses of lean and fat at the butt end were measured directly below the pelvic bone.

Each ham was then analyzed physically and the weights and percentages of the separable lean, fat, bone, and skin determined. From

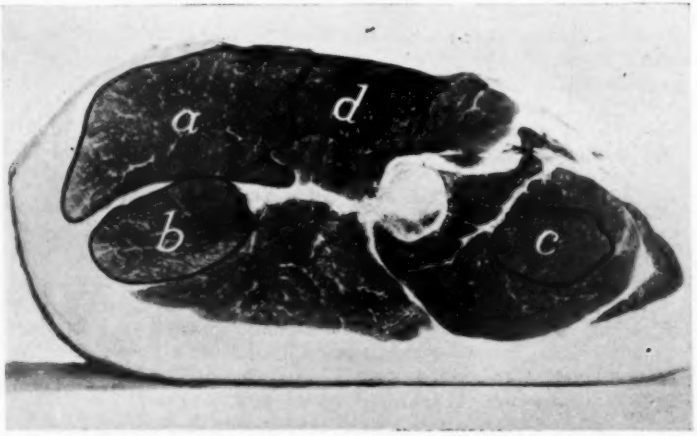

FIGURE 1.—Cross section of ham showing location of muscles studied: *a*, Semimembranosus, *b*, semitendinosus, *c*, rectus femoris, and *d*, adductor.

the separable lean four muscles consisting of the semimembranosus, semitendinosus, rectus femoris, and adductor were dissected out (fig. 1), weighed, and determination made of their percentages based on the total weight of the ham. All components were weighed to the nearest gram.

Because it was the best criterion known, the index of plumpness was used in this study for comparing the hams with respect to conformation. As a first step in the analysis of the data the hams were divided into nine groups, each group having a five-point interval in index of plumpness. This grouping, together with average weights of the hams and various measurements relating to them, is shown in table 1. Figure 2 illustrates hams having the smallest, average, and largest indexes of plumpness of the 59 hams used in the study. The ham with the smallest index is long, narrow, and lacks thickness, whereas the ham with the largest index is relatively short, wide, and thick. The ham of average plumpness is between the two extremes

[4] HANKINS, O. G., and ELLIS, N. R. PHYSICAL CHARACTERISTICS OF HOG CARCASSES AS MEASURES OF FATNESS. Jour. Agr. Research 48: 257-264, illus. 1934.

with respect to these characteristics. Figure 3 shows the relative size and shape of the four muscles taken from the ham with the average index of plumpness, illustrated in figure 2, *B*.

TABLE 1.—*Relationship of index of plumpness of hams to their average weights and measurements*

Hams (number)	Index of plumpness		Weight of ham		Length of ham	Circumference of ham	Thickness of ham fat	Length of ham per kilogram of weight	Thickness of back fat of carcass from which ham was cut	Length of hind leg of carcass from which ham was cut	Width of carcass through ham to length of hind leg, 1 to —	Final feed-lot weight of hogs from which ham was cut
	Range	Average										
			Lbs.	*Kilograms*	*Millimeters*	*Millimeters*	*Millimeters*	*Millimeters*	*Millimeters*	*Millimeters*		*Lbs.*[1]
9	120.1–125.0	122.7	15.26	6.895	395.1	484.7	25.9	57.4	37.5	594.7	2.17	225.4
14	125.1–130.0	127.6	14.74	6.687	377.9	482.1	26.7	56.7	38.9	567.9	2.05	223.1
11	130.1–135.0	132.7	14.81	6.716	373.9	496.0	30.3	55.8	42.5	564.2	2.01	221.9
9	135.1–140.0	137.4	14.94	6.776	362.9	498.7	31.7	53.6	42.6	545.1	1.90	222.2
4	140.1–145.0	142.8	14.28	6.478	351.5	501.5	28.8	54.3	47.5	535.5	1.87	225.3
2	145.1–150.0	146.9	15.12	6.811	347.0	509.5	28.5	51.0	43.7	521.0	1.81	217.5
3	150.1–155.0	151.2	14.88	6.751	344.0	520.3	35.3	51.0	50.1	507.7	1.73	221.7
4	155.1–160.0	159.2	15.04	6.820	335.3	533.8	35.0	49.3	47.5	497.8	1.69	219.8
3	160.1–178.0	169.1	15.12	6.858	325.7	550.7	38.7	47.8	52.0	485.0	1.62	220.7

[1] 1 pound = 0.454 kg.

SIMPLE RELATIONSHIPS OBTAINED

It was found that the weight of the hams did not vary with the index of plumpness of conformation (table 1). However, the length of ham from the lowest point of the aitchbone to the bony projection at the inside of the hock joint showed a consistent decrease with the improvement in conformation. As would be expected, the length-of-leg measurement from the lowest point of the aitchbone to the coronary band of the foot also showed a close but inverse relation to the increase in plumpness. Circumference of ham increased with plumpness, as would also be expected in view of the fact that the index of plumpness represents the relation between circumference and length of the ham.

Both thickness of ham fat and thickness of back fat increased fairly consistently with increasing plumpness of ham, as indicated in table 1. With increasing plumpness there was an uninterrupted narrowing of the relationship between width of carcass through the ham and length of hind leg, and a tendency for a decrease in length from aitchbone to hock joint per unit of weight of ham. In considering the foregoing relationships, it is well to note that the variation in average final feed-lot weights of the hogs was small.

Table 2 shows that the weights of the semimembranosus, semitendinosus, rectus femoris, and adductor muscles did not consistently increase or decrease with increase in ham plumpness. The same statement applies to the percentages of the semitendinosus and adductor muscles, but the proportion of the semimembranosus muscle tended to increase and that of the rectus femoris to decrease with improvement in conformation. The sum of the percentages of the four muscles showed practically no trend associated with increasing plumpness of the hams. In the percentage of total separable lean meat there appeared to be a slight tendency to decrease with increase in

plumpness. On the other hand, the percentage of separable fat and especially the percentage of total edible meat showed a decided tendency to increase with increase in plumpness of the ham.

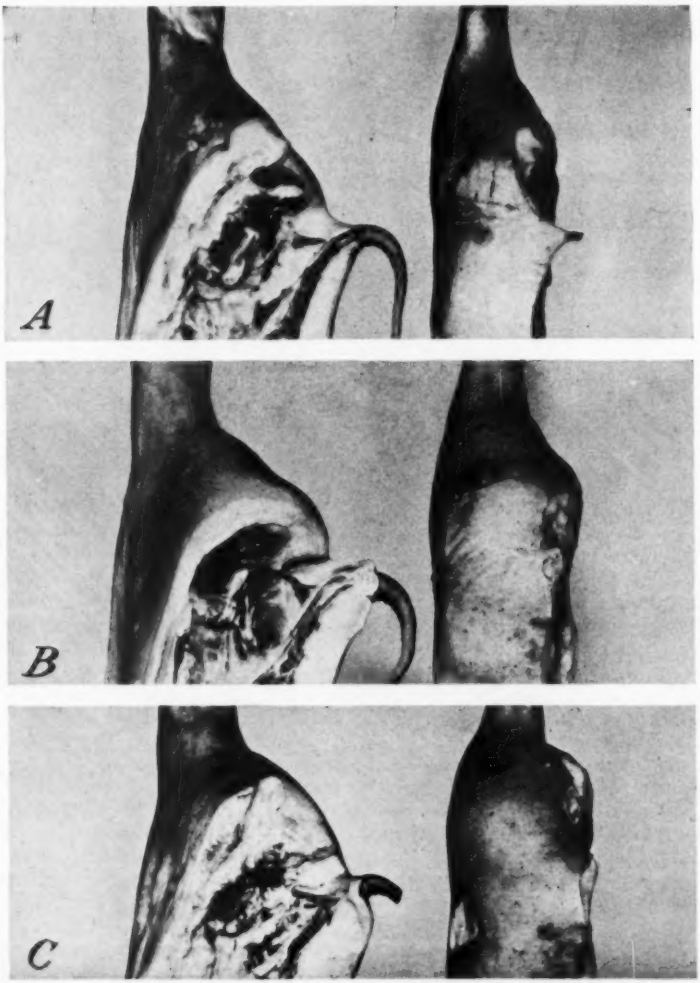

FIGURE 2.—Untrimmed hams having the smallest (*A*), average (*B*), and greatest (*C*) index of plumpness among the 59 hams used in the study. The indexes of plumpness for these three hams were 122.7, 135.5, and 178.0, respectively.

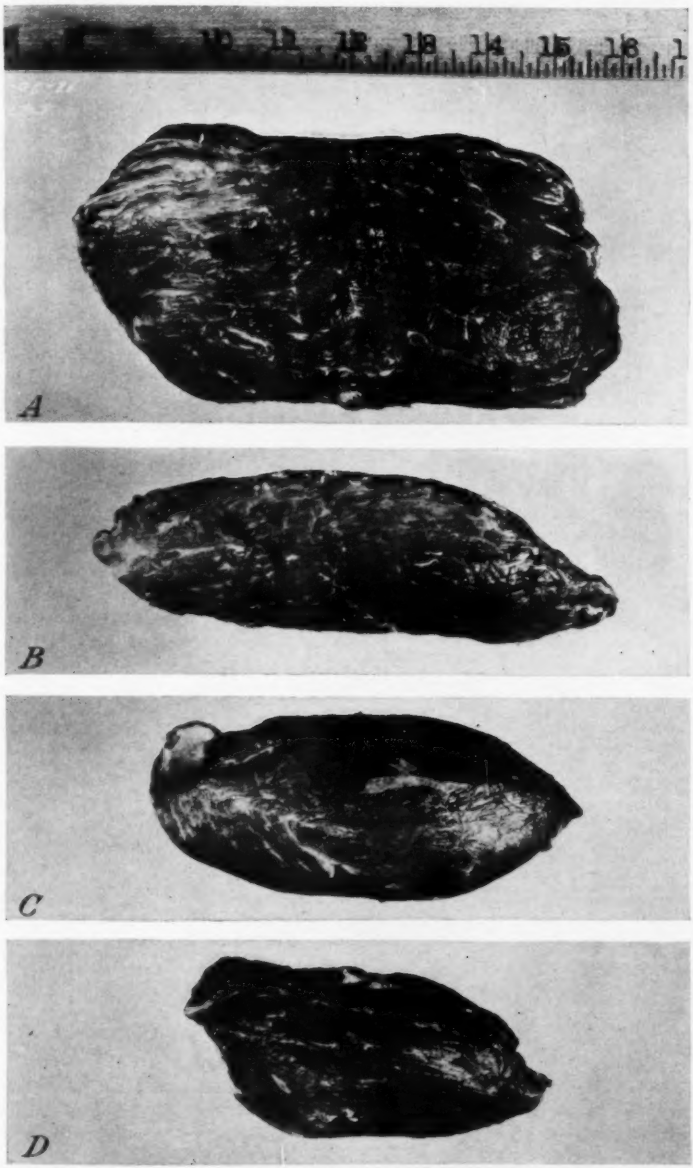

FIGURE 3.—Comparison of size and shape of four muscles taken from ham shown in figure 2, *B*: *A*, Semimembranosus, weight 521.6 gm.; *B*, semitendinosus, 195.0 gm.; *C*, rectus femoris, 249.5 gm.; *D*, adductor, 172.4 gm.

TABLE 2.—*Relationship of index of plumpness of hams to average weights and percentages of the four muscles studied, and percentages of separable fat and lean and total edible meat in the ham*

Hams (number)	Range in index of plumpness	Weight and percentage of muscle								Separable fat	Separable lean	Total edible meat
		Semimembranosus		Semitendinosus		Rectus femoris		Adductor	Total			
		Grams	*Per cent*	*Grams*	*Per cent*	*Grams*	*Per cent*	*Grams*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
9	120.1–125.0	474.8	6.85	253.0	3.65	264.1	3.83	183.0	2.65	16.98	32.51	53.00	85.51
14	125.1–130.0	485.7	7.24	222.3	3.32	248.2	3.71	174.3	2.61	16.88	34.84	51.42	86.26
11	130.1–135.0	440.4	6.57	204.1	3.04	225.2	3.36	160.0	2.38	15.35	38.31	48.35	86.66
9	135.1–140.0	484.8	7.15	200.6	2.96	227.8	3.36	164.3	2.42	15.89	37.65	49.69	87.34
4	140.1–145.0	491.0	7.55	205.3	3.16	229.1	3.52	175.8	2.70	16.93	35.87	51.28	87.15
2	145.1–150.0	544.3	7.99	224.5	3.30	238.1	3.50	188.2	2.77	17.56	35.87	51.45	87.32
3	150.1–155.0	508.0	7.53	214.7	3.17	219.2	3.23	173.9	2.58	16.51	40.70	47.82	88.52
1	155.1–160.0	511.5	7.50	237.0	3.50	232.5	3.40	166.7	2.48	16.88	39.39	49.64	89.03
3	160.1–178.0	514.1	7.47	231.3	3.38	234.4	3.41	175.4	2.57	16.83	40.27	49.53	89.80

RELATIONSHIPS SHOWN BY CORRELATION

To obtain further information on the relationships involved in the study, a number of coefficients of correlation with their probable errors were calculated. The values are shown in table 3. According to Fisher,[5] for P of 0.05, with n of 59, the correlation coefficient must be at least 0.26, and for P of 0.01 the coefficient must be at least 0.33. In table 3 coefficients of 0.26 to 0.32, inclusive, are considered significant and those of 0.33 or more as highly significant.

TABLE 3.—*Coefficients of correlations (with probable errors) of index of plumpness, percentages of separable fat and lean, and weight of ham with indicated factors*

Item	Index of plumpness, r	Percentage of separable fat, r	Percentage of separable lean, r	Weight of ham, r
Percentage of separable fat of ham	+0.58±0.06		−0.90±0.02	
Percentage of separable lean of ham	− .28± .08			
Weight of muscle:				
Semimembranosus	+ .21± .08			+0.64±0.05
Semitendinosus	− .08± .09			+ .60± .06
Rectus femoris	− .26± .08			+ .63± .05
Adductor	− .06± .09			+ .47± .07
Percentage that muscle is of total ham:				
Semimembranosus	+ .27± .08	−0.32±0.08	+ .26± .08	
Semitendinosus	− .10± .09	− .56± .06	+ .59± .06	
Rectus femoris	− .38± .08	− .78± .04	+ .75± .04	
Adductor	+ .02± .09	− .46± .07	+ .50± .07	
Total four muscles	+ .02± .09	− .66± .05	+ .75± .04	
Thickness of ham fat	+ .37± .08	+ .79± .03	− .64± .05	− .04± .09
Thickness of back fat	+ .77± .04	+ .61± .06	− .38± .08	− .13± .09
Ratio of length of hind leg to width of carcass through ham	+ .87± .02	− .47± .06	− .28± .08	
Ratio of edible to inedible portion in ham	+ .79± .03	+ .62± .05	− .23± .08	+ .32± .08

Table 3 shows that percentages of separable fat and lean, thickness of ham fat, and ratio of edible to inedible portion of ham had highly significant or signficant correlations with the index of plumpness. The highest among these values, +0.79, represented the relation between the ratio of edible to inedible portion of ham and plumpness, and the next highest value, +0.58, the relation between percentage of

[5] FISHER, R. A. STATISTICAL METHODS FOR RESEARCH WORKERS. Ed. 5, 319 pp., illus. Edinburgh and London. 1934.

separable fat and plumpness. As shown by the table, the relation between percentage of separable lean and plumpness was inverse.

Squaring the values mentioned gives 0.62 and 0.34, respectively, as the coefficients of determination for (1) plumpness and percentage of edible meat and (2) plumpness and separable fat. These values indicate that 62 percent of the variance in index of plumpness was associated with a single factor—percentage of edible meat—and that 34 percent of the variance was associated with changes in percentage of separable fat.

Of the four muscles considered, the weight of only one, the rectus femoris, was significantly related to ham plumpness, the coefficient being a negative value (table 3). With respect to percentage, the semimembranosus muscle was significantly related to plumpness and the relationship of the rectus femoris muscle was highly significant but inverse. The percentages of the semitendinosus and adductor muscles had little, if any, relation to the plumpness or conformation of the hams. The same statement applies also to the sum of the percentages of the four muscles.

Both average thickness of back fat and the ratio of length of hind leg to width of carcass through ham had highly significant and relatively close relationships with plumpness of hams. The corresponding coefficients of determination were 0.59 and 0.76.

Since of the several ham characteristics considered the percentage of separable fat was most closely related to plumpness, its relationships with certain other factors were studied. The coefficients representing these relationships are also shown in table 3. Of the correlations between the percentage of separable fat and the percentages of the four muscles, three are highly significant and the fourth, relating to the semimembranosus muscle, is significant. All four coefficients are negative, as would be expected. For the total percentage of the four muscles with percentage of separable fat the correlation coefficient, -0.66, was highly significant. The corresponding coefficient of determination was 0.44. Percentage of separable fat was closely related to thickness of ham fat and somewhat less closely related to the ratio of edible to inedible portion of the ham.

The very close inverse relationship between the percentages of separable lean and fat is noteworthy. The relationships of the percentages of the four muscles with percentage of separable lean varied considerably, the coefficients ranging from $+0.26 \pm 0.08$ for semimembranosus, which incidentally was much the largest and heaviest of the four muscles studied, to $+0.75 \pm 0.04$ for rectus femoris. Attention is directed especially to the fact that percentage of separable lean was not a good index of the ratio of edible to inedible portion of ham, although the correlation coefficient was close to the lower limit of the range of significance.

As shown in table 3, the correlations between the weights of the four muscles and weight of ham were highly significant. In none of the four instances, however, was r particularly high. Little relationship was found between thickness of ham fat or thickness of back fat and ham weight. Of greater importance is the fact that ham weight proved to be of little value as an indicator of the proportion of edible meat. The much greater value of the plumpness index for this purpose should not be overlooked.

As already stated, length of ham from aitchbone to hock joint per unit of weight decreased as the index of plumpness increased. A scatter diagram (fig. 4) suggested a curvilinear relationship, and by using a simple parabola the correlation was found to be $\rho=0.82$. The coefficient of determination in this instance was 0.67.

As an additional step, several coefficients of multiple correlation were determined, each representing the relation of index of plumpness,

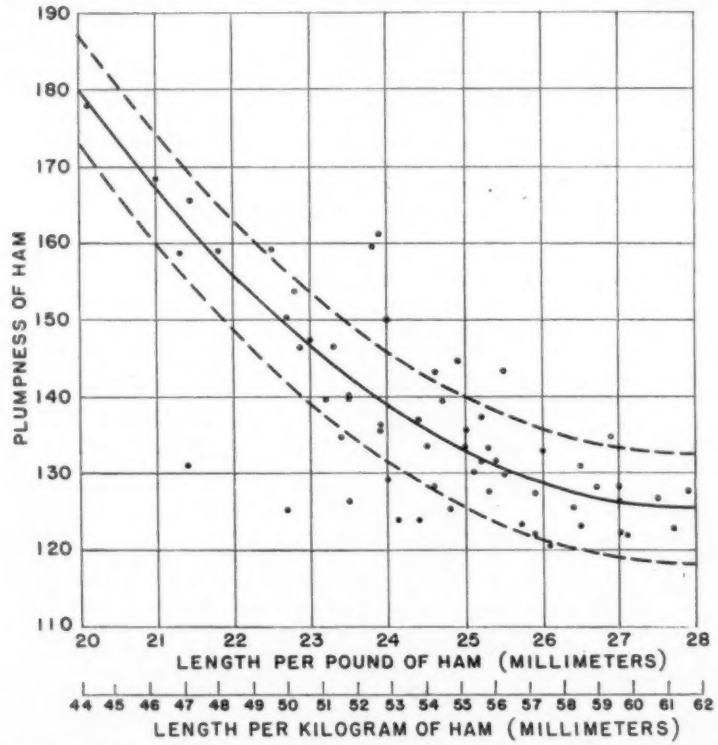

FIGURE 4.—Scatter diagram of index of plumpness and units of length per unit of weight of 59 hams, with curve of average relationship and zones of estimate.

as the dependent variable, to two other ham characteristics. The reason for so doing was the belief that variations in ham conformation might be due more to combinations of factors than to single factors, such as percentage of separable fat and percentage of semimembranosus muscle. As already shown, the simple correlation between index of plumpness and percentage of semimembranosus muscle was $+0.27\pm0.08$ and that between index of plumpness and percentage of rectus femoris muscle -0.38 ± 0.08. The coefficient of multiple correlation, representing the relationship among these three factors, was found to be 0.55. Among the percentages of semimembranosus muscle and separable lean and the index of plumpness the coefficient

of multiple correlation was 0.50. Higher values, 0.62 and 0.80, respectively, were found for the correlations among percentages of separable fat and semimembranosus muscle and index of plumpness and among percentages of separable fat, total percentages for the four muscles, and index of plumpness.

As shown in table 4, the weights of the four muscles were correlated with one another. All the coefficients were positive and highly significant. The semitendinosus and rectus femoris muscles were most closely related, and the semitendinosus and adductor muscles least closely related.

TABLE 4.—*Correlations (with probable errors) between weights and between percentages of four muscles in 59 hams varying widely in conformation*

Item	Weight of—		
	Semimembranosus muscle	Semitendinosus muscle	Rectus femoris muscle
Weight of—			
Semitendinosus muscle	0.54±0.06		
Rectus femoris muscle	.65± .05	0.73±0.04	
Adductor muscle	.66± .05	.51± .07	0.66±0.05

Item	Percentage in total ham of—		
	Semimembranosus muscle	Semitendinosus muscle	Rectus femoris muscle
Percentage, in total ham, of—			
Semitendinosus muscle	0.30±0.08		
Rectus femoris muscle	.40± .07	0.56±0.06	
Adductor muscle	.60± .06	.74± .04	0.70±0.05

In the percentages of the several muscles, all correlation values, with one exception, were highly significant and all were positive. In the one instance, involving the relation between the semimembranosus and semitendinosus muscles, the coefficient was significant. Of the six relationships represented, the correlation between the semitendinosus and adductor muscles was highest. In general, the adductor muscle was most closely related to the other three. In all cases except the relationships between the semitendinosus and adductor muscles and between the rectus femoris and adductor, the correlation values for weights were higher than for percentages.

SUMMARY AND CONCLUSIONS

Study was made of 59 hams from Poland China hogs slaughtered at approximately 225 pounds of weight to determine the relationships of certain anatomical factors to conformation or plumpness.

When the hams were divided into nine groups according to increasing plumpness, no corresponding increase in average weights was found. Length of ham and length of leg decreased, whereas circumference of ham, thickness of ham fat, and thickness of back fat increased with plumpness fairly consistently. Also, there was a narrowing of the ratio of width of carcass through hams to length of hind leg and a decrease in length per unit weight of ham.

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Semimembranosus, semitendinosus, rectus femoris, and adductor muscles did not consistently increase or decrease in weight with increase in ham plumpness. Proportion of semimembranosus muscle tended to increase and that of rectus femoris to decrease, but the sum of the percentages of the four muscles showed no trend. Percentages of separable fat and total edible meat increased with increasing plumpness, whereas the percentage of lean decreased slightly.

Percentages of separable fat and lean, thickness of ham fat, and ratio of edible to inedible portion of the ham had highly significant or significant correlations with plumpness. With separable lean the relation was inverse.

Only in the case of the rectus femoris muscle was weight significantly correlated with ham plumpness, the coefficient being negative. In percentage the relationship of the semimembranosus muscle was significant and that of the rectus femoris highly significant but inverse. Average thickness of back fat and ratio of width of carcass through hams to length of leg were relatively closely related to ham plumpness.

Correlations between percentage of separable fat and the percentages of the four muscles were highly significant or significant, and negative.

Close inverse relation existed between the percentages of separable lean and fat. The relationships of the four muscles to separable lean varied considerably, that of rectus femoris being closest. Percentage of separable lean was not a good index of the ratio of edible to inedible portion of the ham.

Correlations between weights of the four muscles and weight of ham were highly significant, although in no instance particularly high. Little relation occurred between thickness of ham fat or back fat and ham weight. Index of plumpness had much greater value than ham weight as an indicator of the proportion of edible meat.

Close, inverse, curvilinear relationship was found between length of ham per unit of weight and plumpness.

Multiple correlations indicated that variation in ham conformation was due more to combinations of certain factors than to single factors, but percentage of fat had more effect than any other single characteristic studied.

Weights of the semitendinosus and rectus femoris muscles were most closely related, and the former and the adductor muscle least closely related. With respect to percentages, the correlation between the semitendinosus and adductor muscles was highest and in general the latter was most closely related to the other three.

The reader is reminded that these results were obtained from a limited number of hogs of one breed. Therefore it seems a logical conclusion that possibly they are of more value for application to hams from hogs within a breed than to hams from hogs that vary as to breed.

A FOLIAR DIAGNOSIS STUDY OF THE EFFECT OF THREE NITROGEN CARRIERS ON THE NUTRITION OF ZEA MAYS[1]

By WALTER THOMAS, *professor of plant nutrition*, and WARREN B. MACK, *professor of vegetable gardening, Pennsylvania Agricultural Experiment Station*

INTRODUCTION

In a recent paper (*6*)[2] the mode of nutrition of *Zea mays* growing on plots 1 to 9 of tier 1 of the Jordan fertility plots of the Pennsylvania Agricultural Experiment Station were compared by the method of foliar diagnosis (*4*). The carrier of nitrogen in the aforementioned plots is dried blood. Other carriers of nitrogen also are being tested in this long-continued experiment while the carriers of phosphorus and of potassium remain unchanged, the ratio $P_2O_5:K_2O=12:12.5$ being identical in all plots in the entire tier.

In a further examination of the uses to which the method of foliar diagnosis may be applied, the mode of nutrition of *Zea mays* subjected to treatments with complete fertilizers having dried blood as the carrier of nitrogen was compared with that with sodium nitrate as the carrier. A comparison of the mode of nutrition resulting from these treatments was then made with that of the treatment (manure+lime) giving the maximum yield, and the data were examined to determine the relationship of the foliar diagnosis to the yields. The results of this examination are reported in this paper.

Criticisms of the method of foliar diagnosis have been made that ignore some of the fundamental principles upon which the method is based, and have been explained in many of the writers' previous papers (*4*, *5*, *6*), in which emphasis has been placed upon the fact that the method is comparative just as diagnosis by means of the analysis of entire plants also is comparative (*2*). No physiological significance can be attributed to the foliar diagnosis of any one fertilizer (plot) considered alone and apart from the others (*4*). Accordingly, criticisms to the effect that the method does not take into account the action (if any) of rain water in removing soluble nutrients or of the possible return of nutrients from the plant to the soil are irrelevant, because neither the process of migration of the elements into the leaf from the stem or branch nor export from the leaf is under consideration in the method of foliar diagnosis, but only the amount of the element present in the chosen leaf at the moment of sampling. And, furthermore, it must be stressed that all the experiments carried out to test the validity of the method (*4*, *5*) have been made under all sorts of climatic conditions.

The meteorological conditions will affect the mode or quality of nutrition. This influence will be indicated by its effect on the $N-P_2O_5-K_2O$ equilibrium and possibly also on the intensity of nutrition of the selected leaf. There is then a "chemism" due to the meteoro-

[1] Received for publication February 27, 1939. Paper No. 854 in the Journal Series of the Pennsylvania Agricultural Experiment Station.

[2] Italic numbers in parentheses refer to Literature Cited, p. 313.

logical factor as well as a "chemism" due to the fertilizer itself. The mode of nutrition as expressed in foliar diagnosis of a given species in a given year is the resultant of both the meteorological factors and the fertilizer factor.

MATERIALS AND METHODS

The experiments were conducted on the Jordan fertility plots which were described previously (*6*). The plots studied in the present investigation together with their treatments and yields are listed in table 1.

TABLE 1.—*Plots studied, nitrogen sources, treatments, and yields*

Plot No.	Source of nitrogen	Treatment	N, P_2O_5, and K_2O equivalent applied to each plot	Symbol and ratio	Yield per plot	
					Grain	Stover
			Pounds		*Pounds*	*Pounds*
22	Manure	Manure+lime	8.88 (N) 4.00 (P_2O_5) 6.88 (K_2O)		770.8	408.9
9 and 17	Dried blood	Dried blood	3.0	NPK, 6:12:25	520.6	213.0
		Superphosphate	6.0			
		Muriate of potash	12.5			
25	Sodium nitrate	Sodium nitrate	3.0		705.5	359.5
		Superphosphate	6.0			
		Muriate of potash	12.5			
11 and 21	Dried blood	Dried blood	9.0	(3N) PK, 18:12:25	527.6	233.2
		Superphosphate	6.0			
		Muriate of potash	12.5			
28	Sodium nitrate	Sodium nitrate	9.0		722.7	372.6
		Superphosphate	6.0			
		Muriate of potash	12.5			

The method of leaf sampling was similar to that already described (*4, 5, 6*). The third leaf from the base was sampled from each plant in a row lengthwise across the plot. Successive rows were sampled at the dates recorded in table 2.

PRESENTATION OF RESULTS

The plot numbers, treatments, and yields are shown in table 1. The percentages of N, P_2O_5, and K_2O in the third leaf from the base of the stalk at the various sampling dates are given in table 2, together with their milligram-equivalent values and the composition of the NPK unit representing the equilibrium between N–P_2O_5–K_2O at the moment of sampling.

DISCUSSION AND INTERPRETATION OF RESULTS

In the following discussion, for the sake of simplicity and to avoid repetition, the treatment or treatment symbol, or both, either with or without the plot number, is used to indicate the composition of the third leaf from the base of plants growing on the plots receiving the treatment designated.

TABLE 2.—*Percentages of N, P_2O_5, K_2O, CaO, and MgO in the dried foliage, milligram-equivalents, and the composition of the NPK unit for plants grown under the different fertilizer treatments*

Date	Mineral content of dried foliage						Milligram-equivalents				Composition of the NPK unit		
	N	P_2O_5	K_2O	$N+P_2O_5+K_2O$	CaO	MgO	N	P_2O_5	K_2O	S	X	Y	Z
	$(M)_x$	$(M)_y$	$(M)_z$	s			(E_x)	(E_y)	E_z	$E_x+E_y+E_z$	$\left(100\times\frac{E_x}{S}\right)$ N	$\left(100\times\frac{E_y}{S}\right)$ P_2O_5	$\left(100\times\frac{E_z}{S}\right)$ K_2O
	Percent	*Percent*	*Percent*		*Percent*	*Percent*							
6 TONS MANURE+CAO (PLOT NO. 22)													
July 6	3.530	0.538	2.740	6.808	2.793	0.630	252.042	22.757	58.362	333.161	75.652	6.831	17.518
July 21	2.910	.574	2.752	6.236	3.160	.717	207.774	24.280	58.618	290.672	71.481	8.353	20.166
Aug. 8	2.640	.510	2.092	5.242	3.381	.760	188.496	21.573	44.559	254.628	74.028	8.472	17.500
Aug. 25	2.540	.550	2.163	5.253	3.263	.851	181.356	23.265	46.072	250.693	72.342	9.280	18.378
NPK.N AS DRIED BLOOD (PLOTS NOS. 9 AND 17)													
July 6	2.920	0.415	3.906	7.241	1.590	0.457	208.845	17.554	83.208	309.607	67.455	5.670	26.875
July 21	2.380	.466	3.880	6.726	1.862	.534	170.289	19.711	81.589	271.589	62.700	7.258	30.041
Aug. 8	2.550	.562	3.054	6.166	1.775	.363	182.070	23.772	65.050	270.892	67.211	8.777	24.013
Aug. 25	2.460	.645	2.776	5.881	1.740	.327	175.644	27.283	59.134	262.061	67.024	10.411	22.565
NPK.N AS $NaNO_3$ (PLOT NO. 26)													
July 6	3.410	0.412	3.837	7.659	1.933	0.471	243.474	17.428	81.728	342.630	71.060	5.087	23.853
July 21	2.960	.488	3.643	7.091	2.313	.670	211.344	20.642	77.596	309.582	68.268	6.668	25.065
Aug. 8	2.740	.566	2.946	6.252	2.237	.453	195.636	23.942	62.750	282.328	69.294	8.480	22.226
Aug. 25	2.330	.570	2.267	5.167	2.207	.525	166.392	24.111	48.287	278.760	69.678	10.098	20.224
(3N) PK.N AS DRIED BLOOD (PLOTS NOS. 11 AND 21)													
July 6	2.860	0.402	4.306	7.568	1.26	0.403	204.204	17.004	91.718	312.926	65.256	5.434	29.309
July 21	2.565	.479	3.732	6.776	1.52	.464	183.141	20.261	79.502	282.904	64.737	7.162	28.102
Aug. 8	2.615	.496	2.973	6.084	1.56	.568	186.711	20.980	63.327	271.018	68.892	7.741	23.367
Aug. 25	2.740	.610	2.752	6.102	1.68	.606	195.631	25.887	58.618	280.136	69.834	9.240	20.925
(3N) PK.N AS $NaNO_3$ (PLOT NO. 28)													
July 6	3.420	0.426	3.406	7.299	1.994	0.508	244.188	18.020	72.549	334.757	72.945	5.383	21.672
July 21	3.070	.511	3.585	7.166	2.100	.634	219.198	21.615	76.360	317.173	69.110	6.815	24.075
Aug. 8	2.860	.536	2.865	6.261	2.146	.471	204.204	22.673	61.024	287.901	70.929	7.875	21.196
Aug. 25	2.800	.610	2.791	6.201	2.150	.480	199.920	25.803	59.448	285.171	70.105	9.048	20.846

NITROGEN

At the first date of sampling (July 6) the content of nitrogen of the leaf was greatest in the treatment giving the highest yield (manure + lime, plot No. 22), and was followed in descending order both with respect to nitrogen content and yields by (3N)PK (plot No. 28); NPK (plot No. 26), in which nitrogen is in the form of

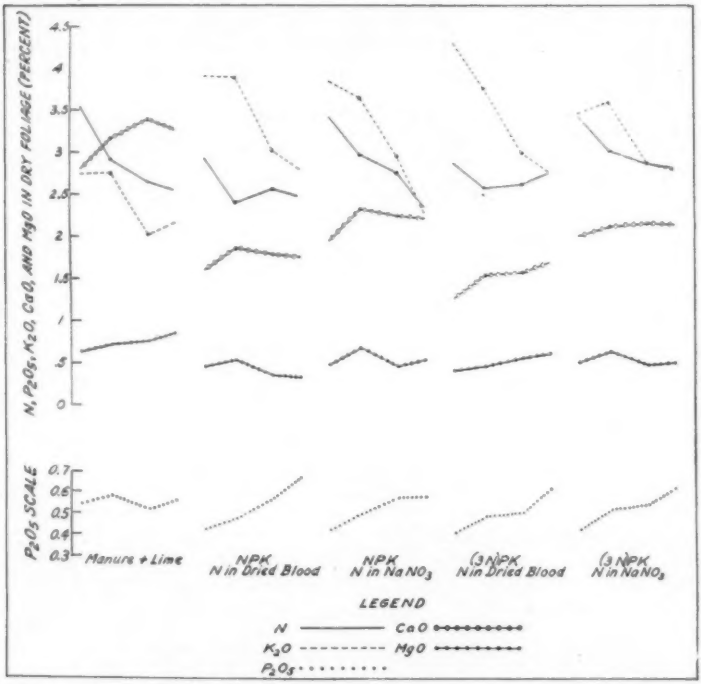

FIGURE 1.—The percentages (dry basis) of nitrogen, phosphoric acid, potash, lime, and magnesia in the third leaf of plants growing in plots receiving the treatments indicated are plotted as ordinates and dates of sampling as abscissae. The dates of sampling (July 6, July 21, August 8, August 25) are indicated by the four dots in each curve.

sodium nitrate; and then by NPK (plots Nos. 9, 17) and (3N)PK (plots Nos. 11, 21) in which nitrogen is in the form of dried blood. At this date, then, there is a relationship between the nitrogen in the leaf and the yields. But this superiority in nitrogen content of manure + lime (No. 22) does not continue with advancing age of the leaf, for, as the relative steepness of the graphs (fig. 1) indicates, the great demand for nitrogen relative to supply of the plants growing on manure + lime (No. 22) causes the graph of this treatment to fall below that of the next highest yielding plot (3N)PK (No. 28) during the remainder of the growth cycle. The nitrogen graph of manure + lime, however, is still above those resulting from the

dried blood treatments, except towards the end of the last period in (3N)PK (Nos. 11 and 21).

Nitrogen in dried blood, then, supplied nitrogen at a lower level of nutrition than did manure + lime or sodium nitrate—an indication of slow availability. Not only do the graphs indicate slow availability of the nitrogen of dried blood in these plots which have never received lime additions, but also the ascent of the graphs indicate in addition that the utilization also is poor.

PHOSPHORIC ACID

At the first date of sampling (July 6) the P_2O_5 content of the selected leaves from the highest yielding treatment, manure + lime (plot No. 22), was the greatest. This superiority of manure + lime continued up to the middle of the second period (about August 1). At the latter date an accumulation of P_2O_5, which occurs both in the sodium nitrate and dried blood plots, causes the graphs of these treatments to rise above that of manure + lime (plot No. 22).

During the first period the differences in the P_2O_5 content of the selected leaf of plants receiving the dried blood and sodium nitrate treatments are insignificant. With advancing age greater differences are noticed, but no regularity is apparent. Accumulation with age, as shown by the ascent of the graphs, occurs in all treatments, and is especially marked in the graphs from the lower application of dried blood. Accumulation of P_2O_5 is insignificant in the manure treatment.

Accumulation of P_2O_5 with the advancing age of the leaf is an abnormal behavior. In plants hitherto examined, the content of P_2O_5 decreased with the advancing age of the leaf.

When nitrogen is plotted against phosphoric acid in the manner described in an earlier paper (*3*), and as shown in figure 2, it is found that relative to the optimum graph indicated by the line $y=2.109x+0.488$, P_2O_5 is too low relative to N during the early period, and too high during the last period in all of the plots examined in the experiments reported in this paper.

POTASH

During the greater part of the first two periods (July 6–21, and July 21–August 8) the potash content was highest in the chosen leaves of plants growing on the dried-blood plots (Nos. 11, 21) which received the highest amount of nitrogen and which gave next to the lowest yields of the treatments considered in this paper. These are followed in descending order of potash content of the leaf during this period by NPK (Plot Nos. 9 and 17), NPK (plot No. 26), (3N)PK (plot No. 28), and manure + lime (plot No. 22). If the dried blood treatments are considered together, the potash content of the selected leaves during this period is in the reverse order of the respective yields. During the last period, August 8–25, there was little difference between the content of the leaves growing on the dried-blood plots, but because of small demand relative to supply in (3N)PK (plot No. 28) receiving sodium nitrate, the potash content of the leaf was slightly above that of those receiving dried blood. In effect "luxury consumption" of potash occurred in the plots which have never received lime. This excess absorption of potash has been harmful to yields—an illustration of the reciprocal effects between calcium and potassium (*1*).

LIME

The graph for CaO is highest throughout the whole period in the limed manure plot (No. 22), followed in descending order of position

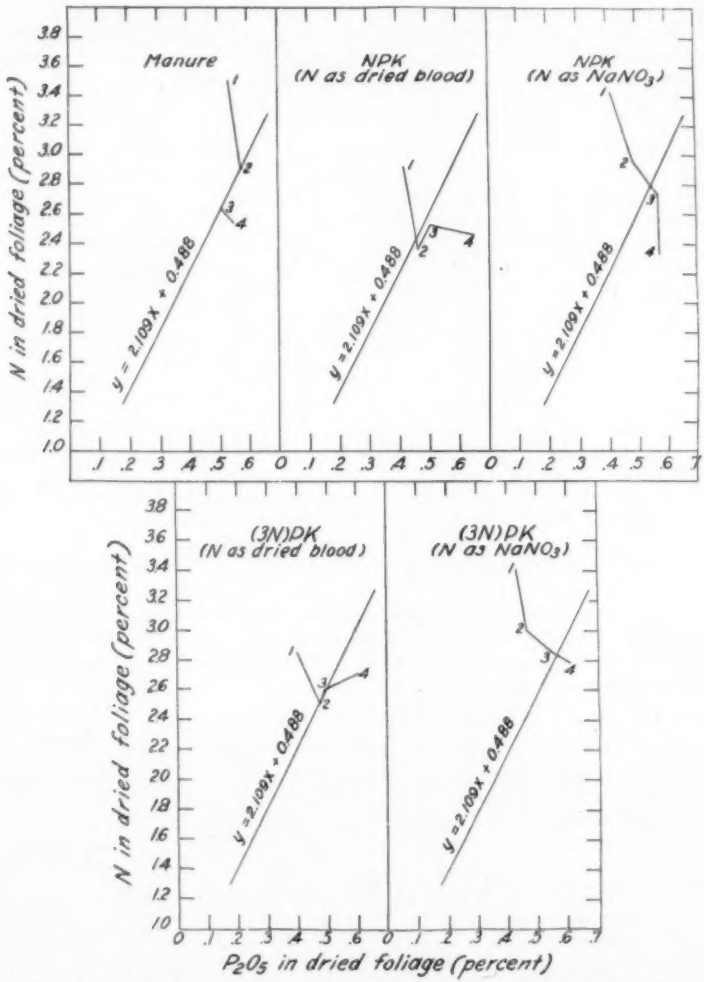

FIGURE 2.—Relation of the percentages of nitrogen and phosphoric acid in the third leaf of plants growing on plots receiving the treatments indicated, at the different dates of sampling: *1*, July 6; *2*, July 21; *3*, August 8; and *4*, August 25.

by NPK (plot No. 26), (3N) PK (plot No. 28), and then by the dried-blood plots NPK (Nos. 9 and 17) and (3N)PK (Nos. 11 and 21). The fact that the graphs of No. 26 and No. 28 with sodium nitrate treatments are always well above the corresponding graphs from the

dried blood treatments is an indication of the greater availability of calcium under sodium nitrate treatments.

Because of the extreme sensitivity of the method of foliar diagnosis the influence of one element on the absorption of another is readily detected. Because of this influence there can be no a priori right to use the quantity of an element in a fertilizer as a variable in the interpretation of results of the effects of fertilizers. An element may be readily absorbed and utilized, but nevertheless may have an injurious effect on growth, because of the effect on the absorption of another element. An illustration occurs in the Jordan plots where added potash has decreased the yields. Thus NK (plot No. 7) has given lower yields than N (plot No. 2), and the foliar diagnosis of these plots (*6*) shows that the effect is the result of the depression of the absorption of CaO in the leaves of plants growing on NK(plot No. 7) (plot No. 7) which is below not only the N treatment, (plot No. 2), but even below that of the check (plot No. 1).

In the present experiments the addition of nitrogen as sodium nitrate (plots No. 26 and 28) by reducing the content of potash in the selected leaves nearer to that of the optimum, manure+lime (plot No. 22), has resulted in an elevation of the CaO graph nearer to that of the optimum, with improved yields.

MAGNESIA

The MgO graphs in general bear the same relation to one another as do the CaO graphs.

INTENSITIES OF NUTRITION AND THE COMPOSITION OF THE NPK UNITS

The interpretation of the data is simplified if only the three plastic elements nitrogen, phosphorus, and potassium are taken into consideration. There are logical grounds for this position; for although there may be no a priori right to relate the composition of a leaf based on the entities nitrogen, phosphoric acid, and potash alone, nevertheless field tests are conducted on the assumption that the other factors for the plots to be compared are either equal or nearly so. Hence it is apparent that if, in any experiment, this assumption is not valid, then the basis for the calculation of probabilities is subject to question. The agronomist then is faced with the dilemma that he must either relate differences in yield to the nutrition of the plant as in the method of foliar diagnosis or draw conclusions on the basis of probabilities computed with assumptions of which the validity may be questionable. If, then, the three elements which are plastic in nutrition and upon which the cost of fertilizers is based, are considered, a fertilizer can intervene in the nutrition of a plant to cause a change in the quantity (or intensity of nutrition) or in the quality (physiological ratios of the elements), or in both simultaneously. The former (intensity) is the sum of the plastic elements ($N+P_2O_5+K_2O$) expressed as the percentage of the dry weight of the leaves, and the quality is best expressed as the NPK-unit which represents the equilibrium between $N-P_2O_5-K_2O$ in the chosen leaf at the moment of sampling. The NPK-unit is derived (*4*, *6*) by converting the percentage values into milligram equivalents and then finding the proportion which each

of these bears to the milligram-equivalent total. The results are then multiplied by 100 to avoid fractional quantities.

The intensities of nutrition and also the composition of the NPK units from one sampling date to another are shown in the fifth, and in the last three columns of table 2, respectively. The NPK units are plotted in trilinear coordinates in figures 3 and 4.

THE INTENSITIES OF NUTRITION

The higher applications of nitrogen either as dried blood or as sodium nitrate had little effect on the intensity of nutrition, except at the last sampling; at this date the intensity was much higher in the dried blood plots which received the higher nitrogen application. With one exception (NPK, No. 26), on August 25, the intensity resulting from the manure + lime treatment (No. 22) was lower than any considered. This reduction in intensity was the result of reduction in the absorption of potash.

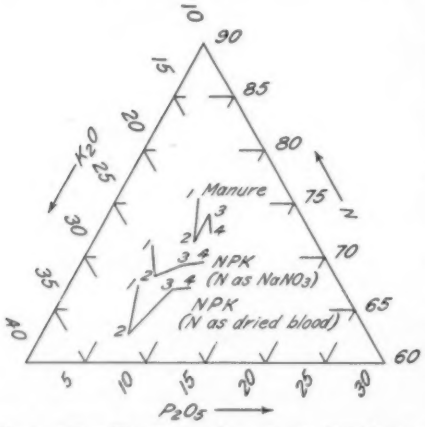

FIGURE 3.—The composition of the NPK units of the third leaf of plants growing on the manure and NPK plots, at the different dates of sampling: *1*, July 6; *2*, July 21; *3*, August 8; and *4*, August 25.

COMPOSITION OF THE NPK UNITS

The changes in the $N - P_2O_5 - K_2O$ equilibrium from one sampling to another are best followed from the graphs showing the changes in the NPK unit (figs. 3 and 4).

During the first two periods (July 6–21, and July 21–August 8) the different treatments have produced similar displacements in direction in the equilibrium between $N-P_2O_5-K_2O$, although the magnitudes of these displacements are unequal.

During the first period all treatments result in a decrease in the nitrogen in the NPK unit, indicating that at this early period the fertilizer is unable to overcome the declining tendency of the medium (soil and meteorological factors) with respect to nitrogen, with the advancing age of the leaf.

As the season advances all graphs reverse their direction, and the quota-part of nitrogen now increases at the expense of the potash in the NPK unit, indicating that the declining tendency of the medium with respect to nitrogen has been checked and even reversed. In manure (No. 22) and (3N)PK (No. 28) the quota-part of nitrogen in the unit again decreases.

The P_2O_5 in the NPK unit increases with advancing age of the leaves in all treatments. This increase is made at the expense of the nitrogen in the first period (July 6–21); at the expense of the potash in the second period (July 21–August 8) and either at the expense of

the nitrogen (manure+lime, plot 22, and (3N)PK, plot 28) or of the potash in the third period (August 8–25).

The qualitative pattern is thus in general similar for all treatments. Quantitatively, however, differences occur and are best considered by means of the mean values of the NPK units during the cycle (fig. 5).

THE MEAN INTENSITIES AND THE MEAN NPK UNITS

The mean intensities and the mean NPK units represent the mean of the respective values during the growth cycle given in table 2 for the intensities and NPK units, respectively, at the four sampling dates; these are shown in table 3. The values of the mean NPK units can be represented by a point on a trilinear diagram (fig. 5), and each point represents the center of gravity of the respective diagrams of figures 3 and 4.

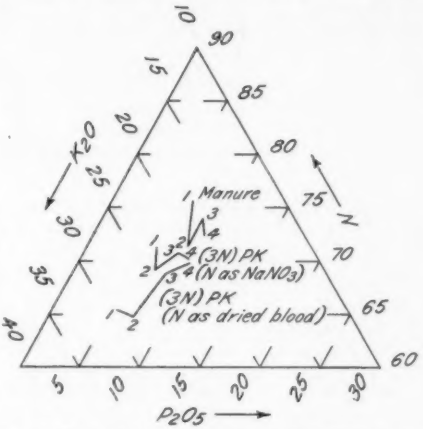

FIGURE 4.—The composition of the NPK units of the third leaf of plants growing on the manure and (3N)PK plots, at the different dates of sampling: *1*, July 6; *2*, July 21; *3*, August 8; and *4*, August 25.

TABLE 3.—*The relation of the mean intensities of nutrition and the composition of the mean NPK-unit to yields of grain*

Plot No.	Treatment	Source of nitrogen	Mean intensity	Composition of the mean NPK unit	Yield of grain per plot
					Pounds
22	Manure+CaO	Manure	5.88	73.38:8.23:18.39	770.8
28	(3N) PK	$NaNO_3$	6.73	70.77:7.28:21.95	722.7
26	NPK	do	6.54	69.57:7.58:22.84	705.5
11, 21	(3N) PK	Dried blood	6.63	67.18:7.39:25.42	527.6
9, 17	NPK	do	6.50	66.08:8.03:25.88	520.6

THE MEAN INTENSITY

The values for the mean intensity are slightly higher for the higher applications of nitrogen than for the lower. As before noted, the values of the manure+lime treatment are much lower than for the other plots.

THE MEAN NPK-UNITS

The composition of the mean NPK-units, on the other hand, is distinctly affected by the source of nitrogen. Relative to the dried blood treatments, sodium nitrate has resulted in an increase in the nitrogen, principally at the expense of the potash.

Increased applications of nitrogen either as dried blood or as sodium nitrate also have resulted in a decrease in the P_2O_5, the effect being greater with the former than with the latter.

RELATION OF YIELDS TO POSITION ON THE TRIANGLE

The composition of the mean NPK-unit of the third leaf from the optimum yielding plot (manure+lime) is $N:P_2O_5:K_2O=73.4:8.2:18.4$. The next highest yielding plot is (3N) PK (No. 28) with nitrogen in the form of sodium nitrate, of which the value of the mean NPK-unit is 70.5:7.3:22.1 and is located nearest to the position of the optimum. This is followed in yield and position on the triangle by the sodium nitrate plot receiving the lower application of nitrogen (No. 26), with a mean NPK-unit of $N:P_2O_5:K_2O=69.6:7.6:22.8$.

The relatively low yielding plots NPK (Nos. 9 and 17) and (3N)PK (Nos. 11 and 21) having nitrogen in the form of dried blood are further removed from the position of the optimum; and the lowest yielding plot of those considered in this paper is the farthest removed from the position of the optimum. There is consequently complete agreement of the foliar diagnosis of leaves of plants on these plots with the facts concerning the culture of the plots. Furthermore, with all growth conditions favorable, it is a logical postulate to maintain that any modification of the soil of plots 9, 11, 17, 21, 26, and 28 that will cause the foliar diagnosis of the leaves of plants on these plots to approach, or coincide with the position of the optimum (plot No. 22), will cause the yields of these plots to approach or to be equal to that of the optimum-yielding manure+lime plot.

FIGURE 5.—Relative positions of the mean NPK units of the third leaf from plants growing on plots receiving nitrogen from the sources shown. The mean NPK unit represents the center of gravity of the respective graphs of figures 3 and 4.

SUMMARY

The foliar diagnosis of *Zea mays* growing on the Jordan fertility plots treated with (1) manue+lime, (2) a complete fertilizer with nitrogen in the form of (a) dried blood and (b) sodium nitrate, both without lime, the sources of phosphoric acid and potash remaining unchanged, gives the following indications:

The absorption and utilization of nitrogen and phosphorus is best and at a higher plane of nutrition in (1) and least and at a low level in (2 (a)).

Sodium nitrate has a greater effect in inhibiting the absorption of potash than has dried blood, but its effect is not so great as that of lime. The seat of this influence resides in the soil and not in the plant.

The effect of the various treatments on the intensities of nutrition and on the $N-P_2O_5-K_2O$ equilibrium during the growth cycle is

described, and the latter magnitudes are shown in trilinear coordinate diagrams. In relation to the optimum treatment (manure+lime), the intensities of the other treatments discussed in this paper are too high. Nitrogen and phosphoric acid in the NPK unit are too low, and potash is too high.

The positions of the mean values during the growth cycle of the NPK-units for a particular treatment in relation to that of the optimum treatment show a definite correlation with yields.

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